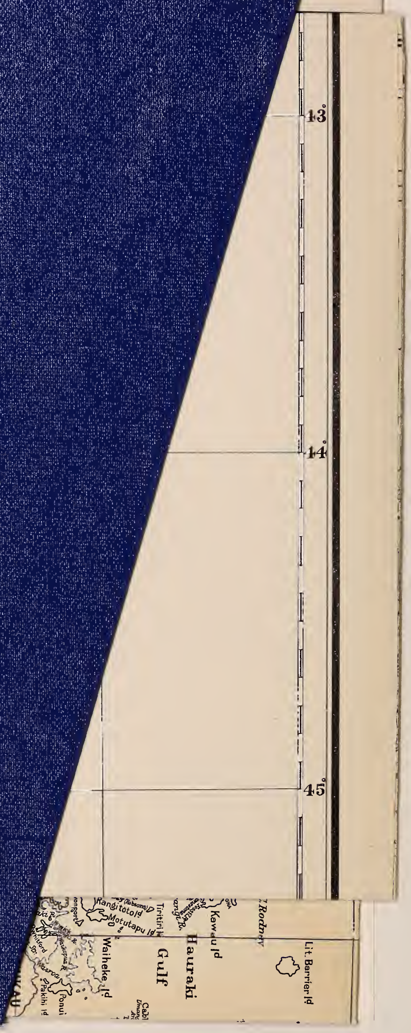
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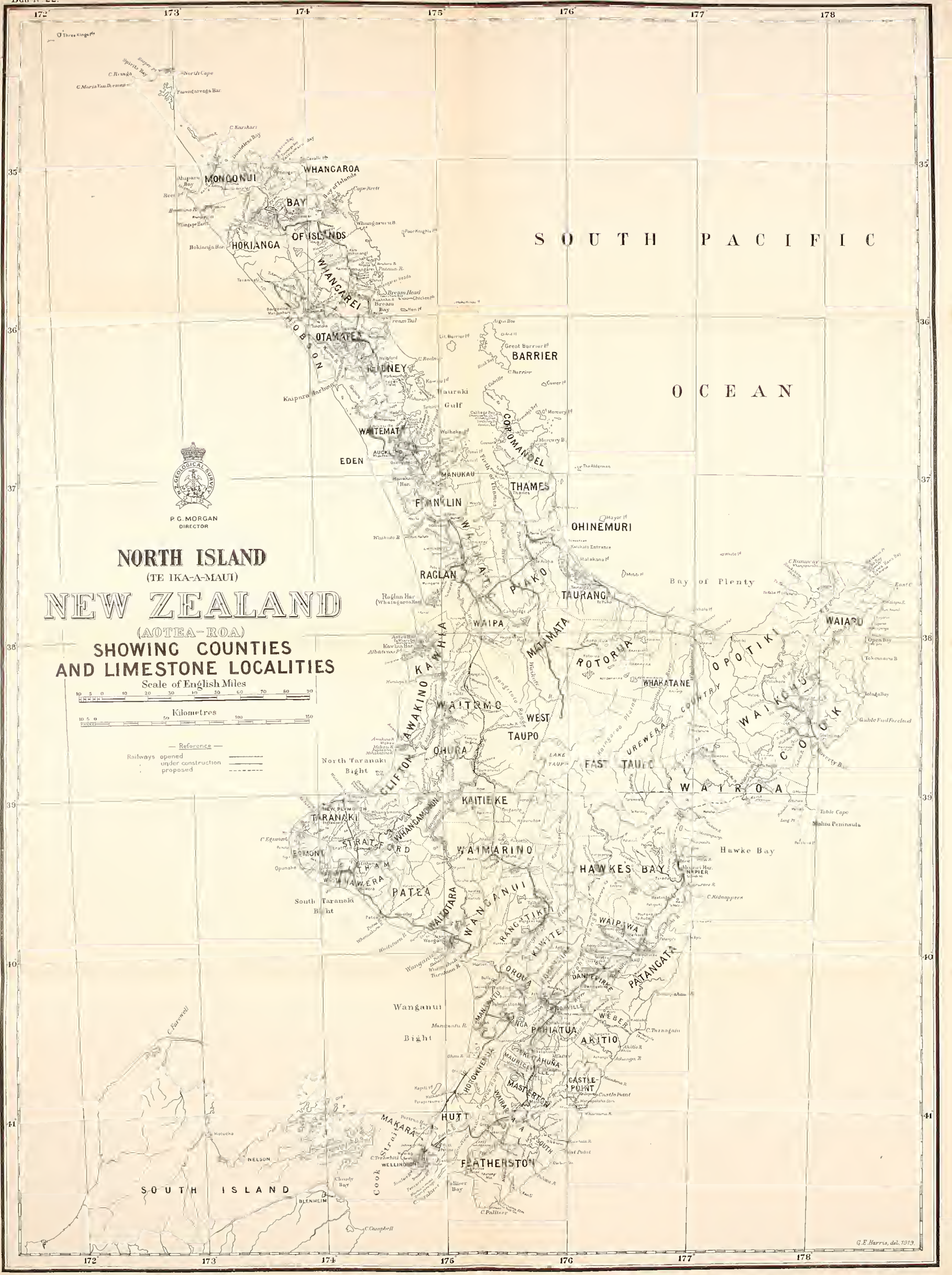


P. G. MORGAN
DIRECTOR

NORTH ISLAND
(TE IKA-A-MAUI)
NEW ZEALAND
(AOTEA-ROA)
SHOWING COUNTIES AND LIMESTONE LOCALITIES

Scale of English Miles

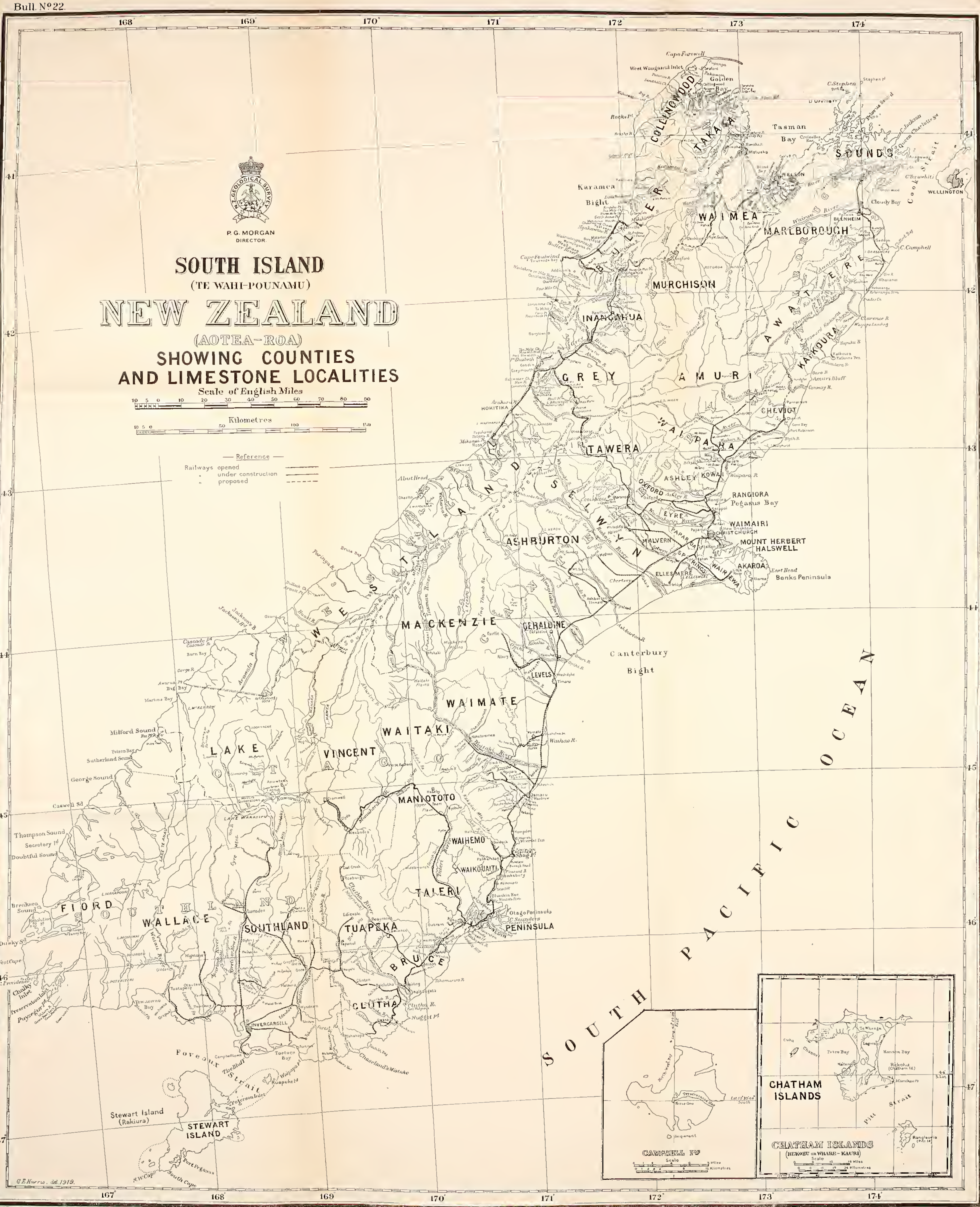
Kilometres

— Reference —

Railways opened
under construction
proposed

G. E. Harris, del. 1913.

Bull. N°22.



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NEW ZEALAND.

Department of Mines.

GEOLOGICAL SURVEY BRANCH.
(P. G. MORGAN, Director.)

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BULLETIN No. 22 (NEW SERIES).

THE LIMESTONE AND PHOSPHATE RESOURCES OF NEW ZEALAND

(CONSIDERED PRINCIPALLY IN RELATION TO AGRICULTURE).

PART I.—LIMESTONE.

BY

P. G. MORGAN

(Assisted by Officers of the Geological Survey: J. Henderson, M. Ongley, G. E. Harris, and F. Fulton-Wood).

ISSUED UNDER THE AUTHORITY OF THE HON. W. D. S. MacDONALD, MINISTER OF MINES.

WELLINGTON.
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1919.

LETTER OF TRANSMITTAL.

Geological Survey Office,
Wellington, 1st August, 1919.

Sir,—

I have the honour to submit herewith Part I of Bulletin No. 22 (New Series) of the Geological Survey Branch of the Mines Department. This bulletin is entitled "The Limestone and Phosphate Resources of New Zealand," and its preparation was undertaken at the request of the Department of Agriculture, which, for the sake of the agricultural industry, desires a comprehensive report on the limestone deposits of the Dominion.

Part I of the bulletin, now presented, in addition to general information on the subject of limestone gives a full summary of all available information concerning the various known deposits in this Dominion. It contains 316 pages of letterpress, together with fourteen plates, six text-figures, and two maps. Part II, which will not be so long, is to consist of a general account of the plant and machinery used in the calcination and the pulverization of limestone, followed by a description of the phosphate deposits of this country. To this information it is hoped to add a supplementary chapter on limestone.

I have the honour to be,
Sir,
Your obedient servant,
P. G. MORGAN,
Director, New Zealand Geological Survey.

The Hon. W. D. S. MacDonald,
Minister of Mines, Wellington.

PREFACE.

Several years ago the Department of Agriculture asked the Mines Department if the Geological Survey would prepare a detailed account of the limestone deposits of New Zealand. A desire that descriptions of machinery used in pulverizing limestone should be included in the report was also expressed. In consequence I promised to write a bulletin which would contain all available information on the subject of limestone in New Zealand. Had I realized, however, the amount of work involved in the task, and foreseen the difficulties that were to arise owing to the prolongation of the war and the demands caused by other work on the time of my staff and myself, it is safe to say that I would not have made the promise mentioned, and that the bulky report now issued would not have been written for years to come. It was, however, by means of much overtime work, practically completed at the end of July, 1918, but, owing to the shortage of paper and other causes, the manuscript was not forwarded to the printer till early in this year. In consequence of this delay further information has been obtained, and in part has been inserted as the report was passing through the press, but the reader will realize that there are limits to additions of this kind.

In order to obtain data for this report Dr. J. Henderson, Mr. M. Ongley, and myself visited numerous localities where limestone exists. Moreover, in the course of the ordinary surveys and inspections of the Geological Survey, each of us had seen and mapped many outcrops of limestone, the information so gained being, of course, available for the present publication. Special reports on limestone deposits were obtained from Messrs. A. J. Baker and H. H. Sharp, District Engineers, through the courtesy and assistance of Mr. R. W. Holmes, Chief Engineer, Public Works Department. Important sources of information were the reports of the Geological Survey published many years ago while Sir James Hector was Director, and the bulletins published by the Survey after its reorganization early in 1905 with Dr. J. M. Bell as Director.

Most of the analyses of limestone found in the literature consulted have been reprinted in full, some are given in part only, and a few are merely mentioned. Many of the analyses are of small value, and some objection to their insertion may therefore be made, but their republication will perhaps be of assistance to future investigators of our limestone deposits. Moreover, it emphasizes the fact that more exact and detailed analyses, made upon carefully chosen samples, will be in many, if not all, cases a necessary part of their investigations.

The main object of this report—namely, to describe limestone deposits that may be of use for agricultural purposes—has already been stated. The information given will also be helpful to those interested in limestone for other reasons, such as its availability for cement-manufacture or for roadmaking. The insertion of such matter as lists of literature, references to the sources of the various analyses quoted, and brief descriptions of the general geology of many counties, increases the size of the report without materially adding to its value for the general reader, but it is thought that these additions will be appreciated by specialists.

It is hoped that the readers of this report will not be disappointed because it inadequately describes the limestone deposits of their immediate neighbourhood, or fails to state how the limestone may be worked to the best advantage. Much remains to be done, but probably it will not be necessary to write another monograph on New Zealand limestone for many years to come. Future reports, whether issued by the Geological Survey or by the Department of Agriculture, will probably be confined in their scope to comparatively small districts, such as a county, or part of a county, and may be expected to give prominence to matters of local interest.

In conclusion I have to thank all the members of the Geological Survey staff for their willing co-operation in the compilation of this bulletin. Assistance in obtaining data has been received from Messrs. B. C. Aston and A. McTaggart, of the Agricultural Department. Several of the Inspectors of Mines and others have also helped in one way or another. Last, but not least, thanks are due to the Government Printer and his staff not only for the excellence of the typographical work, but for the pointing-out of several errors, inconsistencies, or omissions in the text. Past experience, however, shows that in spite of all care a few small mistakes may be expected to occur. If any reader should observe statements requiring correction he is requested to be kind enough to inform me of them, so that a list of errata and corrigenda may be prepared for Part II of this bulletin.

P. G. Morgan.

CONTENTS.

Page
LETTER OF TRANSMITTAL .. iii
Preface .. v

CHAPTER I.—GENERAL INFORMATION.

Page
Introduction .. 1
Advice to Readers .. 2
Functions of Lime in Agriculture .. 3
Amount of Lime required by Soils .. 3
Non-agricultural Uses of Lime and Limestone 4
Military Importance of Limestone and Lime 5
Problems .. 5
(1.) Relative Merits of Quicklime, Slaked Lime, and Ground Limestone .. 5
(2.) Plant for calcining Limestone .. 7
(3.) Plant for pulverizing Limestone .. 7
(4.) Fineness of pulverized Limestone .. 7
(5.) Transport of Lime and Limestone .. 8
(6.) Large Central *versus* small Local Plants 8
Definitions of Limestone, Quicklime, &c. .. 9
Chemistry of Lime and Lime Compounds .. 9
Interpretation of Chemical Analyses .. 12
Constituents of Limestone .. 14
Silica .. 14
Alumina .. 14
Iron Oxides .. 14
Lime .. 15
Magnesia .. 15
Carbonic Anhydride .. 15
Moisture .. 15
Organic Matter .. 15
Page
Chemistry of Lime and Lime Compounds—*continued.*
Constituents of Limestone—*continued.*
Loss on Ignition .. 15
Phosphoric Anhydride .. 15
Other Constituents .. 16
Nature of a Chemical Analysis .. 16
Lime-bearing Minerals .. 16
Tests for Lime and Limestone .. 19
Geology of Limestone .. 20
Origin of Limestone .. 22
I. Mechanically formed Limestone .. 22
II. Chemically formed Limestone .. 22
III. Organically formed Limestone .. 23
Altered and Metamorphic Limestones .. 23
Mode of Occurrence of Limestone .. 23
Geological Systems and the Geological Time-scale .. 24
Definitions of some Geological Terms .. 26
Sampling Limestone .. 26
Quartering down .. 28
Quarry sampling .. 28
Systematic sampling .. 28
Literature .. 30
Additions to Literature .. 33

CHAPTER II.—LIMESTONE IN THE NORTH ISLAND.

Page
Method of Presentation .. 35
County Boundaries; Maps used, &c. .. 36
1. Mangonui County .. 36
2. Whangaroa County .. 41
3. Hokianga County .. 43
4. Bay of Islands County .. 44
5. Whangarei County .. 48
6. Hobson County .. 56
7. Otamatea County .. 58
8. Rodney County and Kawau Island .. 63
9. Waitemata County .. 66
10. Eden County .. 71
11. Manukau County .. 71
12. Franklin County .. 73
13. Barrier County, Little Barrier Island, &c. 73
14. Coromandel County .. 74
15. Thames County .. 76
16. Ohinemuri County .. 77
17. Raglan County .. 79
18. Waikato County .. 83
19. Piako County .. 84
20. Tauranga County .. 85
21. Kawhia County .. 85
22. Waipa County .. 87
23. Matamata County .. 88
24. Rotorua County .. 89
25. Whakatane County .. 89
26. Opotiki County .. 90
27. Waiapu County .. 91
28. Waikohu County .. 93
29. Cook County .. 96
30. Awakino County .. 99
Limestone near Mahoenui .. 99
Limestone near Awakino Village .. 99
31. Waitomo County .. 102
32. West Taupo County .. 107
33. East Taupo County .. 108
34. Wairoa County .. 109
35. Hawke's Bay County .. 111
Page
36. Clifton County .. 115
Limestone, Mokau River .. 115
37. Ohura County .. 117
38. Kaitieke County .. 118
39. Taranaki County .. 119
40. Stratford County .. 121
41. Whangamomona County .. 125
42. Waimarino County .. 126
43. Egmont County .. 127
44. Eltham County .. 128
45. Waimate West County .. 129
46. Hawera County .. 129
47. Patea County .. 130
48. Waitotara County .. 131
49. Wanganui County .. 134
50. Rangitikei County .. 135
51. Kiwitea County .. 137
52. Pohangina County .. 137
53. Waipawa County .. 138
54. Waipukurau County .. 138
55. Patangata County .. 140
56. Dannevirke County .. 142
57. Oroua County .. 143
58. Woodville County .. 144
59. Weber County .. 146
60. Manawatu County .. 146
61. Kairanga County .. 147
62. Pahiatua County .. 148
Pahiatua and Makuri Gorge Deposits 149
63. Akitio County .. 150
64. Horowhenua County .. 152
65. Eketahuna County .. 152
66. Mauriceville County .. 154
67. Castlepoint County .. 156
68. Masterton County .. 157
69. Wairarapa South County .. 158
70. Featherston County .. 160
71. Hutt County .. 162
72. Makara County .. 162

Chapter III.—Limestone in the South Island.

Page
1. Collingwood County 164
2. Takaka County 170
3. Waimea County 174
4. Sounds County 181
5. Marlborough County.. 181
6. Buller County 184
7. Murchison County 192
8. Amuri County 195
9. Awatere County 197
10. Kaikoura County 203
11. Cheviot County 206
12. Inangahua County 208
13. Grey County 211
14. Waipara County 217
Soft-limestone Deposits 219
15. Westland County 224
16. Tawera County 232
17. Oxford County 233
18. Ashley County 235
19. Kowhai County 236
20. Rangiora County 237
21. Eyre County 237
22. Malvern County 237
23. Paparoa County 238
24. Waimairi County 238
25. Heathcote County 238
26. Halswell County 238
27. Springs County 238
28. Mount Herbert County 238
29. Akaroa County 238
30. Wairewa County 238
31. Selwyn County 239
32. Ellesmere County 241
33. Ashburton County 241
Canterbury Plain 243
34. Mackenzie County 245
35. Geraldine County 246
36. Levels County 248
37. Waimate County 249
38. Waitaki County 251
39. Lake County 258
40. Vincent County 264
41. Maniototo County 266
42. Waihemo County 268
43. Waikouaiti County 271
44. Taieri County 273
45. Peninsula County 276
46. Fiord County 277
47. Wallace County 279
48. Southland County 281
49. Tuapeka County 284
50. Bruce County 285
51. Clutha County 288
52. Stewart Island County 288
53. Chatham Islands County and Outlying Islands 289
Appendix to Chapter III 291

Index I.—Localities and General 296
Index II.—Personal Names, etc. 313

PLATES.

Facing page
I. A. Limestone Rocks, Waro, near Hikurangi 20
B. Another View of the Waro Rocks .. ..
II. Limestone Rocks, near Kamo 56
III. A. Limestone, &c., Torehine, Coromandel County 76
B. Limestone Cliffs, near Whangarei .. ..
IV. Limestone Cave, Mahoenui, Awakino County 100
V. Stalactites and Stalagmites, Waitomo Caves 108
VI. A. Limestone, Mokau. Large *Amphistegina* with *Lithothamnium* below .. 116
B. Limestone, Horahora (Whangarei County) with a nearly round *Amphistegina*
C. Foraminiferal Limestone, Milburn (Bruce County) with *Rotalia*, &c. ..
D. Hydraulic Limestone Kaiwaka (Otamatea County) with *Globigerina*.. ..
VII. A. Calcareous Strata, Wanganui River 134
B. Limestone, near Rockville, Collingwood County .. ..
VIII. Limestone Buttes (Hills), in Valley of Aorere River above Rockville 168
IX. A. Cliffs of Calcareous Mudstone near Cape Foulwind 188
B. Cobden Limestone: Quarry on South Side of Grey River .. .. ..
X. A. Nodular Layer in Amuri Limestone, South Side of Amuri Bluff, Kaikoura County 204
B. Contact of Amuri Limestone with Greensand Layer containing Phosphatic Nodules, Port Robinson, Cheviot County
XI. A. View of Trelissick Basin looking South-east from the Summit of Castle Hill .. 232
B. View of Trelissick Basin looking South-west from the Hill between Broken River and Porter River
XII. A. Fluted Limestone at Otaio Gorge 250
B. The Upper Part of Little River Valley viewed from Squire's Farm .. ..
XIII. A. Quarry of Oamaru Stone, Teschemaker's, Waitaki County 256
B. Gay's Oamaru Stone Quarry, near Weston, Waitaki County .. ..
XIV. A. Escarpment of Oamaru Stone running Seaward from Totara, Waitaki County.. 262
B. Quarry of Calcareous Ooze, South-east End of Lake Hayes, Lake County ..

TEXT-FIGURES.

Page
(1.) Nukumaru Limestone, &c. 131
(2.) Section near Kaiwaka Quarries 132
(3.) Section from Takapau Railway-station East to Johnston's Woolshed 139
(4.) Section from North Slope, Tararua Range, to Makakahi Bridge, Pahiatua County .. 148
(5.) Section at Source of Karamea River 184
(6.) Section on Lottery Creek, near Sherwood Station 196

MAPS.

1. Map of North Island, showing Counties, Limestone Localities, &c. .. .. .. At end.
2. Map of South Island, showing Counties, Limestone Localities, &c. .. .. .. At end.

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CHAPTER I.

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	PAGE
Introduction ..	1
Advice to Readers	2
Functions of Lime in Agriculture	3
Amount of Lime required by Soils	3
Non-agricultural Uses of Lime and Limestone	4
Military Importance of Limestone and Lime	4
Problems	5
(1.) Relative Merits of Quicklime, Slaked Lime, and Ground Limestone	5
(2.) Plant for calcining Limestone	7
(3.) Plant for pulverizing Limestone	7
(4.) Fineness of pulverized Limestone	7
(5.) Transport of Lime and Limestone	8
(6.) Large Central *versus* small Local Plants	8
Definitions of Limestone, Quicklime, &c.	9
Chemistry of Lime and Lime Compounds	9
Interpretation of Chemical Analyses	12
Constituents of Limestone	14
Silica	14
Alumina	14
Iron Oxides	14
Lime	15
Magnesia	15
Carbonic Anhydride	15
Chemistry of Lime and Lime Compounds—*continued.*	
Constituents of Limestone—*continued.*	
Moisture	15
Organic Matter	15
Loss on Ignition	15
Phosphoric Anhydride	15
Other Constituents	16
Nature of a Chemical Analysis	16
Lime-bearing Minerals	16
Tests for Lime and Limestone	19
Geology of Limestone	20
Origin of Limestone	22
I. Mechanically formed Limestone	22
II. Chemically formed Limestone	22
III. Organically formed Limestone	23
Altered and Metamorphic Limestones	23
Mode of Occurrence of Limestone	23
Geological Systems and the Geological Time-scale	24
Definitions of some Geological Terms	26
Sampling Limestone	26
Quartering down	28
Quarry sampling	28
Systematic sampling	28
Literature	30
Additions to Literature	33

INTRODUCTION.

New Zealand is blessed with a temperate climate and soils that are naturally fertile, or can be rendered so by the application of scientific methods of farming. By far the greater part of its inhabitants gain their living—for the most part, a comfortable living—directly or indirectly from the soil. The exceptions are those supported by mining and fishing, but neither of these industries is altogether independent of agriculture. If the agriculturist and the soil that he cultivates were removed, few would be the miners and fewer still the fishermen that would venture to the inhospitable shores of the barren land. There is no need to point out that without the soil there could be little human or other life in New Zealand, nor is there need to dwell upon the great wealth that is actually produced by the soil of this country; but there is some need to emphasize the fact that by suitable means the natural productivity of the soil can be greatly increased. Every farmer well knows that various substances applied in due proportion to the soil increase its production, but he does not always know how best to procure the necessary fertilizing agents. Lime is greatly needed by many soils, and, judiciously applied, will improve the production of almost all. In New Zealand there are abundant supplies of limestone for agricultural and other purposes, but the deposits are not everywhere found just where wanted. The main objectives of this bulletin are to indicate the localities where limestone is known to occur, and to give all available information as to the quantity, quality, and accessibility of the deposits. In addition, information concerning the plant and machinery used in the calcination and the grinding of limestone will be given. There will also be a chapter on the somewhat scanty phosphate resources of New Zealand. The preliminary chapter will contain a general account of the chemistry, geology, and mineralogy of lime and limestone. Limestone is important not only for agricultural purposes, but also for the manufacture of cement and many chemicals, as a building-stone, and as a roadmaking material. Hence the information given in this bulletin will be useful to many others besides those interested in the farming industry.

The programme set out is ambitious, and it has not been found possible to cover it in its entirety. Various important localities have either not been visited or have been but casually examined by members of the Geological Survey. The old geological and other reports consulted for additional data do not, nor could they be expected to, give all the information required. They are often vague, and in the attempt to summarize and set out clearly their statements minor errors may well have been made.

It may be as well here to state clearly that there is no intention of claiming for this publication that it is intended to embody all the information that could be obtained by a complete exploration of the limestone and phosphate-bearing areas of this country. Such a course would have involved many years of work; and in particular the sampling alone of the limestone deposits would have required a tremendous amount of labour and great expense. Detailed examination is immediately necessary in some districts, but the present generation cannot undertake the whole of the work. This bulletin represents an endeavour to summarize what is now known, and thus to lay a foundation for future work.

ADVICE TO READERS.

Much of what is written on the following pages will be found superfluous by one reader or another, but it is believed that none of the material will be valueless to every reader. Those who consult this publication for a special purpose, such as information concerning the limestone deposits in their own district, will be able to ascertain what pages should be read by a judicious use of the table of contents and the index. The trained scientist, of course, knows what to skip in his reading, but the non-technical man may conceive that it is his duty to plod laboriously through matter of which he has only the vaguest understanding. The latter is advised that in the first place he should read only what he is interested in or understands. It is hoped, however, that when leisure permits he will make an attempt to grasp the general information given under the headings of "Chemistry," "Geology," "Lime-bearing Minerals," &c. It is especially desirable that the younger readers, who have not reached the age at which the assimilation of new ideas becomes difficult, should endeavour to digest the more purely scientific portions of this bulletin. The effort will do no harm, even if it is a failure. Those who have had the good fortune to be trained in a good agricultural college will have no great difficulty in the matter, and will probably find little that is outside the scope of the college course.

FUNCTIONS OF LIME IN AGRICULTURE.

Lime is indispensable as a component of the bodies of plants and animals. It accumulates in the leaves of plants, but the roots and seeds, as a rule, contain only small quantities. Certain kinds of algæ inhabiting fresh and salt water have their solid parts composed almost wholly of carbonate of lime. A most important function of lime, either in the form of oxide (quick or slaked lime) or of carbonate, is to correct sourness or acidity of the soil. The presence of lime in the soil promotes nitrification. An excess of lime in the form of oxide may, however, hinder the work of the nitrifying organisms until, by the absorption of carbon dioxide from the atmosphere, it is converted into carbonate.

Lime has the property of liberating several classes of plant-food from compounds in the soil. It acts upon decaying vegetation, liberating nitrogen in the form of ammonia, which will be partly taken up by the plants growing upon the soil; but there is a likelihood that some will escape, and hence there is danger of exhausting the soil by the excessive application of lime, especially in the form of quicklime. Again, lime liberates potash from such minerals as feldspar, and makes it available for the use of plants. This is perhaps the most important effect of lime on soil. The heavy application of quicklime may liberate potash at a greater rate than it can be used by the plants growing on the soil; consequently the excess of free potash will probably be lost by leaching, and the result will be the premature exhaustion of the soil. There is every reason to believe that carbonate of lime acts much more slowly than quick or slaked lime in liberating potash or nitrogen; nor does it destroy the humus, as quick and slaked lime do. Hence the following proverbs lose much of their force when carbonate of lime is used as a substitute for quicklime:—

> Lime enriches the father, but impoverishes the son.
>
> Lime and lime without manure
> Will make both farm and farmer poor.

Ultimately, however, especially with certain crops, the application of potash manures to the soil will become necessary. On the other hand, our present knowledge indicates that a proper system of farming in most cases will avoid the necessity of buying nitrogenous manures.

Finally, lime ameliorates the texture of many soils. Clay soils, if given a heavy dressing of quick or slaked lime, become much more friable, and will then respond more readily to cultivation and manuring. Loose sandy soils are rendered more compact by the application of any form of lime, and may thus be considerably improved.*

Amount of Lime required by Soils.

No fixed rules can be given as to the amount of lime required by a soil. Most New Zealand soils would be benefited by the application of from 1 to 2 tons of quicklime every five years. This is best administered in several dressings, but an acid soil may, of course, require a heavy preliminary application. If pulverized limestone is used instead of quicklime nearly double the weight will be required. In Southland the soils as a rule require more lime than in most other parts of New Zealand. Heavy clay land may be much improved, as stated above, by the application of several tons of lime per acre.

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* For further information the reader ought to consult the standard works on agriculture, such as "The Soil," by A. D. Hall; "Soils, their Formation, Properties, Composition, and Relation to Climate and Plant-growth," by E. W. Hilgard; "Agriculture," by William Somerville; "Soils, their Properties and Management," by T. L. Lyon, E. O. Fippin, and H. O. Buckman (New York: The Macmillan Company: 1916); &c. Various articles in the *Journal of Agriculture* by B. C. Aston, J. Brown, A. McTaggart, and others will be found very helpful.

Non-agricultural Use of Lime and Limestone.

From the point of view of the agriculturist the most important use of lime is as a soil-dressing, but in fact far more lime is used for other purposes, some of which touch the farmer very nearly. Lime forms from 62 to 63 per cent. of ordinary Portland cement, and is the principal constituent of a good natural cement—*i.e.*, a calcined and ground argillaceous limestone. Puzzolana cement is a mixture of finely ground volcanic rock and lime. Slag cement is the same thing, with furnace slag taking the place of the volcanic rock. A very large amount of lime is used in the building trade for making mortar. Much lime and limestone are used in chemical industries, such as the manufacture of alkalies, carbon dioxide, glass, chloride of lime, paper, leather, sugar, artificial manures, soap, glycerine, calcium carbide, calcamide, calcium nitrate, &c. Much limestone is used as a flux, especially for iron-ores. Great quantities are used as building-stone and as roadmaking material. Slaked or hydrated lime is the principal ingredient of cold- and hot-water paints (kalsomine, &c.). It is a constituent of many preparations used in the extermination of insects. Chalk is so well known as merely to require mention. Whiting is levigated chalk. Lime is used in the cyanide process of gold-extraction to neutralize the acidity of the ores. Similarly, it is used in steel and tinplate mills to neutralize the acids employed in cleaning, polishing, and burnishing the product. It is also used in purifying water for boilers and for sanitary purposes, in the purification of coal-gas, and in the cleaning of cotton (but not of wool or silk, its action on them being too drastic). Many other uses of lime could be mentioned, but what has been said suffices to show the great importance of good supplies of limestone to any civilized country.

Military Importance of Limestone and Lime.

The following quotation from Bulletin 666 R of the United States Geological Survey, 1917, may be made :—

" All industries, of course, are affected directly or indirectly by the war, but some, owing to the nature of their products, have attracted particular attention. Such, for example, are operations in the iron and steel industry, including the location of armour-plate plants, the manufacture of nitrates and related products, and intensive agriculture. Other industries that would be affected by cutting off of supplies include glass-manufacture (especially for optical work*) and paper-manufacture (for which wood-pulp has been imported). Special problems caused by armies in the field, such as purification of water-supply and of sewage, may also be mentioned. In all of these, as well as many more, limestone is used, and most of them require high-calcium stone of high grade (containing 95 per cent. or more of carbonate). For example, limestone for optical glass must be practically free from iron and aluminum [in English usage, aluminium]; lime for nitrate-manufacture must be as free as possible from silica, alumina, iron, and magnesia.† Although rock of so high a grade forms only a small fraction of the limestone deposits of the country, it is nevertheless sufficiently abundant and accessible to industrial centres."

The bulletin goes on to mention the uses of dolomite or high-magnesium lime in furnace-linings, in the sulphite process of paper-manufacture, and in certain branches of the tanning industry. For most purposes dolomite or magnesian limestone must be fairly free from impurities. Available analyses of American limestone and dolomite in which impurities, especially iron and alumina, are separately and accurately determined are relatively rare, and this statement applies even more forcibly to New Zealand limestones.* The bulletin quoted above goes on to say,—

---

* One may mention lenses for cameras used by airmen and for field-glasses.

† This statement illustrates the value of complete and careful analyses. The purer the limestone the more worth while such analyses are.

> "There is, furthermore, a tendency on the part of some producers of building-lime to investigate the influence of impurities on the workability of the lime and its strength after setting. The need of greater accuracy in limestone-analyses is therefore becoming a matter of general interest to lime-producers, as well as of vital importance to certain industries affected by the present abnormal conditions.
>
> "Limestone and lime for agriculture need not necessarily be of very high grade. Although insoluble impurities tend to lessen the percentage of lime available for improving the soil, they are not actively injurious to plant-growth, and it may be more economical to use a local lime than to go to the expense of purchasing a higher-grade lime in a distant market. . . . The supply of limestone available for agriculture is therefore unlimited [this is true for New Zealand also], and its widespread occurrence and low cost are important factors in the intensive cultivation during war-time of land that, in recent years at least, has not been prepared for the growing of crops. From the fact that limestone and lime, by reacting with minerals of the soil, render such constituents as potash and phosphorus more available, and also aid in the growth of the bacteria that render nitrogen available, it is obvious that lime will not only serve to counteract acidity of soils, but in some soils will serve as a substitute for fertilizers whose price may be expected to rise with a marked increase in demand."

PROBLEMS.

In connection with the use of lime in agriculture several problems present themselves to the farmer and others interested in the matter. Among these are—

(1.) The relative merits of quicklime, of slaked lime, and of ground limestone from an agricultural point of view :
(2.) The best type of plant for calcining limestone :
(3.) The best type of plant for pulverizing limestone :
(4.) The degree of fineness to which limestone should be crushed :
(5.) Transport of lime or crushed limestone from place of preparation to the farm :
(6.) The advisability or otherwise of installing large central lime-burning or lime-crushing plants in order to supply large areas, rather than small units serving only small areas.

(1.) *Relative Merits of Quicklime, Slaked Lime, and Ground Limestone.*

Whether quicklime or ground limestone is to be used in a given case depends upon a number of varying factors. By a consideration of all these a decision can be reached, but sometimes that decision will be in favour of quicklime and sometimes in favour of ground limestone. The ground of controversy then is not whether quicklime or ground limestone is the better, but which is the better in a specified set of circumstances. Quicklime has the advantages that it is more rapid in its action than ground limestone, and that weight for weight it is much higher in lime content than limestone. As will be shown on a later page, 56 parts of pure quicklime is the equivalent of 100 parts of limestone, or 1 ton of quicklime is equivalent to 1·786 tons of limestone. If limestone with 90 per cent. of carbonate of lime be taken as the standard, 1 ton of quicklime produced from it will be equivalent in lime content to 1·656 tons of the limestone itself. As regards cost of transport, quicklime has apparently a great advantage over limestone, but this is offset to some extent by the facts that quicklime usually contains a little unreduced carbonate of lime, and that it tends to become air-slaked, thus absorbing water and carbon dioxide from the air, and increasing somewhat in weight. Quicklime is more troublesome to handle than ground limestone, and requires special protection against premature slaking by rain while it is being conveyed from the kiln to the farm. Quicklime should not be mixed with farmyard or other nitrogenous manures, because, as already indicated, it liberates the nitrogen in the form of gaseous ammonia very rapidly.

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* It would be all but useless, however, to make a high-class analysis of a poorly selected or unrepresentative sample.

Slaked or hydrated lime has almost exactly the same properties as quicklime. It is more easily handled, and if it should become wet will not generate heat. It contains nearly one-quarter its weight of water, and therefore is less effective, weight for weight, than quicklime. For the same reason its transport will be more expensive, a greater weight of slaked lime than of quicklime being required per acre. Theoretically 56 parts of quicklime are equivalent to 74 parts of slaked lime (see also p. 10).

Ground limestone is less rapid but more lasting in its action than quicklime. It costs much less per ton to produce, at least if made on a large scale; but the main point to consider is the cost per ton of contained calcium oxide or lime, and with small plants irregularly operated this may be greater in the case of ground limestone than in the case of quicklime. It is less troublesome to handle than quicklime, does not give rise to any danger of fire, and does not require bagging so frequently as quicklime. Where the cost of transport to the farm is high, limestone is under a serious disadvantage, because approximately $1\frac{3}{4}$ tons of limestone has to be carried for every ton of quicklime. Low-grade limestones cannot be converted into quicklime, but, if the cost of quarrying, pulverizing, and transport is not too high, are quite suitable for use as soil-dressings. Again, soft or friable limestones that require little or no crushing have a decided advantage over lime in the matter of first cost.

On the whole it may be decided that ground limestone is fully equal to quicklime as a soil-improver. There are cases where one is to be preferred to the other, but as a rule the deciding factor will be the cost per unit weight of calcium oxide or pure lime landed on the ground. Analyses are, of course, necessary to determine the amount of lime in each class of material. If quicklime with 85 per cent. of lime costs 30s. per ton delivered on the farm, then ground limestone analysing 51 per cent. of lime will be worth 18s. per ton delivered on the land, for $\frac{85}{30} = \frac{51}{18}$. Some authorities are of opinion that pulverized limestone has a greater value than is indicated by its lime content; so that in the case specified above the ground limestone is worth more than 18s. per ton—say 20s. per ton, or even more. Thus A. McTaggart writes as follows in vol. 12 of the *Journal of Agriculture*, No. 5, May, 1916, page 346:—

"For soils within striking distance from the railway, and not situated more than a few miles beyond the 100-mile limit of free railage, the ground limestone could more economically be used on all soils, but particularly on the lighter soils, provided the price is not more than one-half to two-thirds of that charged for burnt lime. In other words, where 20s. per ton is charged for burnt lime not more than 11s. 3d. per ton should be charged for carbonate of lime.* But other factors render carbonate of lime worthy of a higher value than that just calculated by comparing the two forms on the basis of calcium content. These factors are the inexhaustive nature of carbonate of lime and its consequent suitability for application in large quantities to all types of soil; its agreeable condition to handle for both man and horse as compared with burnt lime; the absence of danger in haulage or in storage when the material gets wet; its special value as a base for nitrate (soluble plant-food) formation; and its action as a carrier of carbon dioxide, whose component parts (carbon and oxygen) are essential plant-foods, and in this form add to what are already enclosed in the soil. Relatively, therefore, anything up to about 15s. per ton may be considered a legitimate price for first-grade carbonate of lime compared with 20s. for the burnt, caustic, oxide, or quick form of lime. Moreover, when burnt lime is applied to the land it ultimately returns to the carbonate form by taking up carbon dioxide from the soil-air."

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* As the sentence stands 13s. 4d. ought to have been written instead of 11s. 3d. The latter price is approximately 56 per cent. of 20s.

Mr. McTaggart therefore estimates that carbonate of lime has three-fourths the value of quicklime, weight for weight, instead of only $\frac{56}{100}$, the proportion obtained by considering the lime (CaO) content only. It will be observed that he definitely assigns considerable value to the carbon dioxide (CO_2) contained in carbonate of lime. The writers have no intention of attempting to settle controversial points, which can better be decided by field and laboratory experiments, but content themselves with the statement that, on the whole, the value of ground limestone is certainly 56 per cent. of the value of quicklime of corresponding purity, and in many cases is more. On the other hand, under certain conditions the use of quicklime is more advantageous than that of ground limestone—for example, where the soil is strongly acid. Quicklime also seems preferable for heavy clay soils. In some cases the so-called impurities of limestone and lime have an agricultural value that can be taken into account. Thus an impure limestone may contain appreciable amounts of phosphate and of potash, and so be of greater value as a soil-dressing than a nearly pure limestone. Considerations like these indicate the desirability and necessity of reliable and complete analyses of limestone, a matter further emphasized on later pages.

(2.) *Plant for calcining Limestone.*

The old-fashioned pot kilns tend nowadays to be replaced by kilns of a different shape, with external furnaces for the fuel, and so arranged as to be operated continuously. These and other improvements have increased the capacity, reduced labour, and improved the product. Modern plants for calcining limestone will be described in Part II.

(3.) *Plant for pulverizing Limestone.*

The choice of machinery for pulverizing limestone will depend very largely upon the scale of operations. In general the plant ought to include (*a*) means for drying the limestone, (*b*) a machine for breaking the stone into small lumps, and (*c*) a machine for reducing the small lumps to a powder. Further discussion of the subject may be usefully postponed to Part II, in which descriptions of various types of pulverizing-machines and drying plants will be found.

(4.) *Fineness of pulverized Limestone.*

Limestone being a soft rock, easily broken down by weathering, it is fairly obvious that there cannot as a rule be any great advantage in reducing it to an extremely fine powder. The finer the state in which it is applied to the soil, however, the quicker will be its action, and in some cases this will be a decided advantage. A little reflection, especially by those who are familiar with the chemical treatment of gold-bearing quartzose ores, will also make it clear that variation in fineness of grain cannot be a detriment to the agricultural use of pulverized limestone, for years are available for the decomposition of the fragments, which will thus ultimately produce their full effect on the soil. The ordinary methods of pulverizing stone give a product of mixed fineness of grain, and therefore it is most convenient to aim at such a product. Other things being equal, the coarser the average grain of the powdered limestone the cheaper it will be to crush, but only in those cases where a uniformly very fine powder is sought will the cost of crushing be excessively great. Hence not the crushing-cost, but experimental work on soils, will ultimately decide the proper fineness of pulverized limestone. The degree of fineness required will vary also with each type of limestone. A hard compact limestone will require finer pulverization than a friable easily weathered stone. Until more experimental work has been done, the following remarks of Dr. Cyril G. Hopkins, a well-known writer on soil science, may be considered authoritative:—

"Carbonate of lime does not need to be exceedingly finely ground, because limestone is quite readily soluble in salt [? soft] water, and if too finely ground there is likely to be great loss by leaching. We do not know yet just the absolutely ideal conditions to which the limestone should be reduced, but I am frank to say that from all the information we have thus far secured I shall not be surprised if, when the data are all in and the final conclusions can be formed, we shall find that the most economical material is that which passes through a quarter-inch screen, including the total product, of course, which will vary from the finest dust up to pieces a quarter of an inch in diameter. Of course, when we make an application of limestone we are thinking of two very important effects. One is immediate results, and the fine material produces that. The other is durability of the effect, and the coarser particles produce that."*

These remarks, attributed to Dr. Hopkins, appear to be taken from an uncorrected report of a speech delivered by him, and therefore he should not be held responsible for the English, which leaves much to be desired, but the sense is clear and good. The reader, however, should bear in mind that there are some agriculturists who consider that ground limestone should pass through a finer screen than that advocated by Dr. Hopkins.

(5.) *Transport of Lime and Limestone.*

The most serious difficulty opposing the widespread use of lime is the cost of transport. The problem is such a general one, affecting as it does the cost of all bulky commodities, that it need not here be discussed in detail. Each district must take local circumstances into account, and solve its own phase of the problem as best it can. For this reason the means of transport are mentioned under each county heading in Chapters II and III.

Two special factors affecting relative cost of transport of lime and crushed limestone are protection from the weather and the cost of bagging. The latter is an expensive item, and whenever circumstances permit lime should be transported in bulk. The cost of transport also has an important bearing on the question of central *versus* local plants.

(6.) *Large Central* versus *small Local Plants.*

Large plants established in suitable positions can produce far more economically than small plants, and this statement is especially true of limestone-crushing plants. The cost of distribution to the farms will decide whether in a given area there should be one central plant or a number of minor plants. In New Zealand the railways carry lime and pulverized limestone for 100 miles free of charge; and this policy, if continued, will greatly favour the establishment of large lime-works at points from 150 to even 200 miles apart. It is only fair, however, that the actual cost of this carriage should be charged against the lime so transported, and taken into account when the construction of large lime-works is contemplated.

Various types of portable machines, more or less suitable for pulverizing limestone on a small scale, are on the market, and in districts where limestone is plentiful there is a tendency to install such plants for the benefit of a single farm or a small group of farms. How far this policy will prevail against that of constructing large lime-works is difficult to say. In districts that are isolated, or a considerable distance from any locality where large works can be suitably erected, the small plant may be advocated, especially if it can be shown that a good type of pulverizer is available. In the future, as the ramification of electric-power cables proceeds over New Zealand, there will doubtless be more and more scope for the small or moderate-sized plant.* The fact that this bulletin deals with New Zealand as a whole almost inevitably leads to the advocacy of the large central plant (see Part II), but this does not necessarily mean that, given favourable conditions, small plants are not to be recommended.

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* From an American publication, *The Canner*, of 29th November, 1917, quoted by B. C. Aston in "Two Notes on Limestone," *Journal of Agriculture*, 20th March, 1918, p. 162.

Definitions of Limestone, Quicklime, etc.

For the purposes of this bulletin *limestone* may be defined as a rock, generally, but not always, of a light colour, which on being " burned " (or, more correctly speaking, calcined) loses considerably in weight, and forms the substance known as quicklime. From a chemical point of view limestone may be defined as carbonate of calcium (or lime) mixed with more or less impurity. *Quicklime* may be described as a caustic earth consisting essentially of calcium oxide, which when mixed with a small amount of water evolves considerable heat, and forms the substance known as slaked lime. If mixed with more water and with sand slaked lime forms a cement or mortar. Chemically, quicklime is oxide of calcium mixed with various impurities. Slaked lime is hydrated oxide of calcium.

It is highly important that the farmer and others should distinguish clearly between quicklime, slaked lime, and limestone, and should not apply the word " lime " indiscriminately to all three substances. In this bulletin the word " lime," if written without a qualifying expression, will be used only in the sense of pure quicklime or of a chemically prepared substance (calcium oxide) having the composition of pure quicklime, and never in the sense of carbonate of lime (calcium carbonate) or of limestone. In such phrases as " the land needs lime," " lime will have to be imported," &c., the word " lime," however, is used with a wider meaning, and includes compounds of lime as well as lime in the form of quicklime.

Chemistry of Lime and Lime Compounds.

In order that the reader may be able to form exact ideas concerning the nature of the three allied but distinctly different substances—quicklime, slaked lime, and limestone—a little elementary chemistry must be introduced. In the first place, theoretically pure quicklime or calcium oxide has been found by the chemist to be a compound substance formed by the union of 40 parts by weight of a metal known as calcium with 16 parts by weight of a gas known as oxygen. Calcium is of a yellow colour, very ductile and malleable. It is only 1·58 times heavier than water, and is thus even lighter than the closely allied metal magnesium. Owing to the cost of preparation, and perhaps to the want of research, at present it has no commercial use. Oxygen, as most people know, forms nearly 21 per cent. by volume, or 23 per cent. by weight, of the air we breathe, and is the substance that supports animal life and most forms of combustion. Both calcium and oxygen are bodies that the chemist cannot (as yet) decompose or split up into simpler substances. He therefore calls them elements, and gives each a symbol —Ca for calcium, and O for oxygen. He tells us that a " molecule " of pure quicklime or calcium oxide is formed by the union of one "atom" of calcium, weighing 40 times as much as an atom of hydrogen (which is the lightest of all known atoms), with one atom of oxygen, weighing 16 times as much as an atom of hydrogen, and symbolically represents the process by an "equation,"* thus: $Ca + O = CaO$.

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* See Parry, E.: " The Economics of Electric-power Distribution," in the *New Zealand Journal of Science and Industry*, vol. 1, No. 1, Jan., 1918, p. 55.

This equation means a great deal to the chemist, but, even so, he is well aware that it by no means represents the whole truth. Still, what the reader should grasp is that, as stated above, pure quicklime, or "lime," or (as the chemist, in order to avoid double meaning, would generally say) "calcium oxide," consists of 40 parts by weight of calcium combined with 16 parts by weight of oxygen. In practice, quicklime as made by calcining or "burning" limestone is not pure, but mixed with varying amounts of sand and other impurities contained in the original limestone.

If water is added to quicklime chemical action takes place, as is indicated by the apparent disappearance of the water and the evolution of heat, and a true union of lime and water is the result. The resulting slaked lime, if the amount of water has been properly adjusted, is just as dry as the original quicklime. The chemist tells us that water consists of 2 parts by weight of the light elementary gas called hydrogen combined with 16 parts by weight of the gas oxygen. Further, he states that the molecule of water (or hydrogen monoxide, as he very occasionally calls it) consists of two atoms of hydrogen combined with one atom of oxygen, and gives the following equation as representing in a very symbolical manner the formation of water: $H_2 + O = H_2O$.

The reader should note the conventional method of expressing the two atoms of hydrogen in the above equation—namely, by writing the figure 2 after and a little below the symbol H, representing the element. A full explanation of the conventions with respect to symbols and equations adopted by the chemist would occupy much space, and reference for such information must therefore be made to text-books on chemistry.

The formation of slaked lime is represented in the following way: $CaO + H_2O = CaH_2O_2$. CaH_2O_2 may also be written $Ca(HO)_2$ or $Ca(OH)_2$. All three symbols mean practically the same thing. It should be noted that the above equation indicates that 56 parts by weight of pure quicklime or calcium oxide combine with 18 parts by weight of water (hydrogen monoxide) to form 74 parts by weight of slaked lime (calcium hydrate). Hence a pure slaked lime contains almost one-quarter its weight of water, and therefore, other things being equal, the carriage of quicklime is less costly than that of its equivalent in slaked lime. Quicklime absorbs water very readily from air, which always contains a certain amount of moisture or water vapour, and thus, if exposed to air for any length of time, becomes "air-slaked." It also absorbs carbon dioxide, referred to in the next paragraph, and therefore tends to revert to its original state of carbonate of lime.

It is well known to most people that there exists in nature a somewhat heavy gas known variously as carbonic-acid gas, carbon dioxide, or carbonic anhydride. Of these names the first, though often used, cannot be recommended, especially when it is incorrectly reduced to the term "carbonic acid." The last may perhaps be considered too technical for everyday use, and therefore the form "carbon dioxide" will here be used. Carbon dioxide, as the name indicates, is found by the chemist to consist of a combination of the element known as carbon (the essential constituent of charcoal) with a double measure of oxygen. The molecule therefore consists of one atom of carbon combined with two atoms of oxygen. The equation for the union is therefore $C + O_2 = CO_2$ [+ much heat].

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* For definitions of the terms "atom," "molecule," and "equation" the reader may consult any standard dictionary. It is felt that to introduce explanations here would render this section of the bulletin cumbrous, without adding materially to its lucidity.

The atomic weight of carbon being 12, the above equation shows that 12 parts by weight of carbon combine, with twice 16 (or 32) parts by weight of oxygen, to form 44 parts by weight of carbon dioxide. The non-technical reader may compare the symbol for carbon dioxide, CO_2, with that for water, H_2O (or OH_2).

Quicklime, as previously mentioned, and slaked lime also have the property of absorbing and combining with carbon dioxide, even when this gas is present only in very small amount, as in ordinary air. For the sake of simplicity, only the equation in which quicklime is concerned will here be given: $CaO + CO_2 = CaCO_3$ [+ heat]. This equation is open to technical objections; but the conclusion to be drawn from it is that 56 parts by weight of pure quicklime can combine with 44 parts by weight of carbon dioxide to form 100 parts of a third substance represented by the symbol $CaCO_3$. This substance is called by the chemist "carbonate of lime," or, more exactly, "calcium carbonate," and represents what would be the composition of a perfectly pure limestone, if such were found in nature. As a matter of fact, limestones containing over 98 per cent. of carbonate of lime do exist, and under certain conditions almost perfectly pure carbonate may be formed.

If carbonate of lime or any form of limestone is strongly heated or calcined* it is decomposed or broken up. The heavy gas, carbon dioxide, is given off, and quicklime remains. The action is represented by reversing the last equation, thus: $CaCO_3$ [+heat] $= CaO + CO_2$.

From this equation we learn that 100 parts of pure limestone or carbonate of lime on being strongly heated give off 44 parts by weight of the gas carbon dioxide, which disappears into the atmosphere, and that 56 parts of quicklime remain behind in the kiln or other apparatus in which the calcination is performed. A simple calculation (1 ton $\times \frac{100}{56}$) shows that it takes 1·786 tons, or over $1\frac{3}{4}$ tons, of pure limestone to produce 1 ton of pure quicklime. Since also $1 \times \frac{74}{56} = 1{\cdot}321$ it is apparent that 1 ton of pure quicklime will produce 1·321 tons of slaked lime. So far as lime, or calcium oxide, is concerned, 1 ton of pure quicklime is therefore the equivalent of 1·321 tons of pure slaked lime or of 1·786 tons of pure limestone. If it be assumed that we are dealing with a limestone containing 90 per cent. of carbonate of lime and 10 per cent. of impurity unaffected by heat, we shall get the following sets of figures:—

A. One ton of quicklime containing 16·56 per cent. of impurities is equivalent in lime content to 1·268 tons of slaked lime containing 13·05 per cent. of solid impurities, together with 21·15 per cent. of water, or 1·656 tons of limestone containing 10 per cent. of impurities.

B. With impurities as in A, 1·198 tons of impure quicklime will contain 1 ton of pure calcium oxide, and will be equivalent to 1·519 tons of slaked lime or 1·984 tons of limestone.

From these data it will be seen that where transport is expensive the advantage is likely to lie with quicklime as against slaked lime, and still more so as against ground limestone. The purer the original limestone the greater the apparent advantage in favour of quicklime; but nevertheless it may not follow that in any given case a limestone ought to be calcined before use for agricultural purposes. The question of ground limestone *versus* quicklime has already been discussed (see pp. 5–7). Transport is only one of several weighty factors to be considered.

Consideration of the nature of the change involved will show that the term "burning" as applied to the operation of converting limestone into quicklime is technically incorrect. In ordinary burning or combustion, as in the case of wood or coal, the oxygen of the air combines with the substance burnt, and heat is produced; whereas in the case of lime-burning there is no consumption of oxygen, and there is no production of heat, but, on the contrary, heat has to be applied, and is absorbed during the process of splitting or breaking up the limestone into lime and carbon dioxide. Hence in a later part of this bulletin the terms "calcining," "calcination," or "calcined" will generally be used instead of the more familiar terms "burning" or "burnt." And here it may be as well to explain that the chief use of scientific terms is to promote exactness of expression and to prevent confusion of meaning. Another use is to enable a reasonable degree of brevity to be attained. The preceding paragraphs may be used to illustrate this latter point. If expressed wholly in "scientific language" they could easily be compressed into one-quarter the space. There are those who use scientific words in such a way as to hide their ignorance, and there are others who use them in order to impose upon the ignorant, or those who, though far from ignorant in general, are unacquainted with the branch of learning professed by the pseudo-scientist. Such objects, it need hardly be said, are not sought by the writers of this bulletin. If any statements in the following pages appear obscure through the use of technical terms the reader will find that his difficulties can be resolved by the intelligent use of a good standard dictionary, or, better still, by consulting the pages of a recognized text-book in chemistry, geology, or whatever may be the branch of science concerned.

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* Under ordinary conditions dissociation or breaking up begins at a temperature of about 800° C. or 1,472° F., but is very slow and imperfect at that temperature. Under lime-kiln conditions the temperature required is about 1,040° C. or 1,904° F. See also Chapter IV (Part II).

Interpretation of Chemical Analyses.

Probably the non-technical reader of this bulletin will find difficulty in understanding the meaning of the numerous analyses quoted, and therefore in this place some explanation of a typical limestone-analysis may be given. Take the following analyses (1) of a rather poor limestone from Awaroa, near Huntly, given in the 50th Annual Report of the Dominion Laboratory, 1917, page 20; and (2) of a good or "fat" limestone from Cape Foulwind, given in the 48th Annual Report, 1915, page 19:—

	(1)	(2)
Silica (SiO_2)	22·52	1·31
Alumina (Al_2O_3)	5·28	0·24
Iron oxides (FeO and Fe_2O_3)	1·84	
Lime (CaO)	36·28	54·60
Magnesia (MgO)	0·23	0·29
Carbonic anhydride (CO_2)	27·24	43·00
Moisture and organic matter	5·09	0·43
Phosphoric anhydride (P_2O_5)	0·17	0·22
Totals	98·65	100·09

The numbers in the above analyses represent the percentages of the different substances isolated by the chemist by means of long and complicated operations, of which the details cannot be given here. The sum of the constituents in analysis No. 1 is 98·65, instead of 100, which theoretically should be the result of the summation. The discrepancy is due partly to the small unavoidable errors of the various determinations, but mainly to the analysis not being quite complete, in that it does not include the alkalies, soda and potash, as well as several other substances which are probably present in very small quantity. The summation of No. 2 analysis is exceptionally good. An eminent chemist* states that the summation of a chemical analysis should be between 99·75 and 100·5 per cent. Since most of the unavoidable errors are plus, an analysis that sums slightly over 100 per cent. is generally preferable to one that sums under 100.

Chemical analyses are usually reported to two places of decimals per cent.—that is, the various constituents are supposed to be determined to one-ten-thousandth part of the original substance. As will be understood from the remarks made above, this degree of accuracy is not, as a rule, quite attained. Many limestone-analyses are incomplete, and made by means of quick time-saving methods, which are in general not so accurate as longer methods. These analyses are usually reported to one place of decimals only. Occasionally a result may be reported to the nearest 1 per cent. only. In such cases, according to a well-known mathematical convention, ciphers should not be placed after the last significant figure, since, if that were done, the analyses would seem to have a greater degree of accuracy than they really possess. In some of the analyses printed on later pages the rule just given has not been followed in the original publications from which they have been quoted, and it may also happen that the rule has been unintentionally broken by the authors of the present bulletin. This matters very little, since it is usually an easy matter to perceive whether the ciphers in an analysis possess any significance or not. Examples of significant ciphers after the decimal point will be observed in analysis No. 2, above.

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* W. F. Hillebrand in U.S. Geol. Surv. Bull. No. 148, 1897, p. 62.

It will be noticed that the analyses are reported in percentages of various compound substances, and not in terms of the elements. The compounds mentioned, with the exception of "organic matter," are oxides—that is, they are formed by the union of oxygen with the various other elements. The reason for reporting analyses in this form is twofold—firstly, the various elements, almost without exception, are actually oxidized; and, secondly, the substances separated and weighed by the chemist are generally oxides. The constitution of an ordinary rock, however, is far more complicated than is shown by its analysis as usually reported. The various oxides are combined more or less intricately with one another, forming a number of minerals, and the rock is composed of a mixture of these minerals. When a thin section of the rock is made and examined with the aid of a petrological microscope fragments or crystals of the various minerals can be distinguished, each, as a rule, with a characteristic appearance. With many rocks the process of arriving at their true constitution is a complicated matter, but in the case of a limestone all that is necessary for most practical purposes can be deduced from its chemical analysis. The "lime" (calcium oxide) of a limestone is combined, for the most part, with the carbonic anhydride or carbon dioxide to form carbonate of lime, or the mineral known as calcite. A little of the lime will be combined with the silica, alumina, iron oxides, &c., thus helping to form one or more minerals in which silica is the leading constituent. Such minerals are collectively known as silicates. A little lime may also be assumed to be combined with the phosphoric anhydride present, thus forming phosphate of lime. The magnesia of the analysis may usually be assumed as all combined with carbon dioxide, forming carbonate of magnesia. Most of the silica in a high-grade or an arenaceous (*i.e.*, sandy) limestone will probably be uncombined, and will appear as a quartz sand.

In the two analyses quoted moisture and organic matter* are given together. In the absence of specific information as to its nature the organic matter may be neglected; in most limestones the amount is very small. Part of the "moisture" of No. 1 analysis is no doubt free uncombined water, and part is more or less loosely combined with clayey matter—silicate of alumina, &c. The limestone represented by this analysis could not be readily dry-crushed until it was dried. In No. 2 analysis the moisture is almost negligible.

To go further into a discussion of the analyses quoted above is perhaps inadvisable. Those with a fair knowledge of chemistry will grasp all the essential points without explanation; those without will probably need personal explanations adapted to each individual case before clear ideas on the subject can be attained. It may, however, be as well to point out that in order thoroughly to understand rock-analyses a considerable knowledge of geology as well as of chemistry is required, and that the seeker after information should avoid, if possible, persons who have only a superficial acquaintance with science. Limestones, however, are comparatively simple rocks, consisting essentially of one mineral, calcium carbonate (calcite), and in most cases the chemist reports the percentage of this mineral. If not so reported it may easily be calculated. Let it suffice to say that analysis No. 1 shows that the limestone is composed of about 62 per cent. of carbonate of lime, with a good deal of clayey matter, a moderate amount of sand (quartz), and small amounts of other substances. The limestone of No. 2 analysis is almost pure carbonate of lime (97 per cent.), with a little carbonate of magnesia, a little sand, and small amounts of silicates, &c. The quite simple methods by which the amount of carbonate of lime can be calculated from an analysis reported in the ordinary form will be given in an appendix to this report.

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* The term "organic matter" as used by chemists includes animal and vegetable matter, and such substances as tar, bitumen, &c., but does not include mineral substances formed by or through the action of animals and plants, such as shells, the hard parts of corals, &c. See also pp. 15, 23.

Constituents of Limestone.

In order to help those who are without technical knowledge, and are unable to obtain the assistance of a competent instructor, yet wish to obtain some insight into the meaning of a rock-analysis, descriptions of each of the substances ordinarily mentioned as constituents in analyses of limestones will now be given.

Silica.—Silica is formed by the union of oxygen with a solid non-metallic element known as silicon. This is indicated by its symbol SiO_2 and its alternative name "silicon dioxide." Next to oxygen silicon is the most abundant of all elements, but is never found in an uncombined or elementary state in nature. It invariably occurs in its oxidized form—namely, silica. Silica may be present in rocks either in the free state—that is, uncombined with other substances—or combined with water only, or combined with various metallic oxides in a more or less complicated manner, forming then what are known as silicates. As formed in the laboratory silica is a white powder, fusible on the application of intense heat. In nature it occurs abundantly as the mineral quartz, of which there are numerous varieties. Much more rarely it forms other minerals, which have the same composition as quartz, but a different crystalline structure. Combined with a little water, silica forms opal and its varieties. The most abundant substances in nature are the silicates alluded to above. With the exception of carbonates, all the chief rock-forming minerals are silicates.

Alumina.—Alumina is the oxide (trioxide) of the metal aluminium or aluminum. The name "aluminum" is the more logical one, and is used in the United States. "Aluminium" is the usual British and European form. Artificially prepared alumina is obtained in the form of a white powder or of gum-like masses, which can be fused by the application of intense heat such as that of the oxy-hydrogen flame. In nature uncombined alumina occurs as intensely hard corundum, coloured forms of which are known as ruby, sapphire, oriental emerald, &c. Combined with more or less water alumina forms several other minerals, known as gibbsite, diaspore, and bauxite, the last-named of which contains also iron oxide, and is the chief source of the metal aluminium. Alumina, however, occurs most abundantly in combination with silica and various metallic oxides, thus forming an essential constituent of a great variety of silicates, important among which are the various species of feldspar. Clay is essentially a silicate of alumina combined with some water.

Iron Oxides.—Iron forms three combinations with oxygen, one of which, ferrous oxide or iron monoxide, with the symbol FeO, is never found free in nature, but always combined with other oxides. A second oxide is ferric oxide, or iron sesquioxide, Fe_2O_3. This occurs in nature as hæmatite, a valuable ore of iron, and is the same in composition as ordinary iron-rust.* The third oxide is magnetic oxide of iron, Fe_3O_4, which is simply a combination of the other two oxides: $FeO + Fe_2O_3 = Fe_3O_4$. In nature it occurs as the mineral magnetite, which is a not unimportant iron-ore. Ferric oxide combined with more or less water forms various minerals, such as limonite, göthite, and bog iron-ore, all important as sources of iron. Iron ochre is hydrous ferric oxide mixed with more or less clay, &c. Iron occurs, however, most abundantly in silicate minerals. In nearly all cases both ferrous and ferric oxides are found in a rock in one or other of the silicates present. In many rock-analyses the iron is all transformed to and weighed as ferric oxide, but in this case the convention is to report the result ostensibly as an undifferentiated mixture of ferrous and ferric oxides. This means that both oxides are present in the rock, but a separation has not been made. In limestone-analyses the discrepancy is not important, but it leads to a small error in the summation. Very often, also, where iron oxides and alumina are low, they are weighed together, and no separation is attempted. A case of this kind is represented by analysis No. 2 on page 12.

Lime.—It has already been explained that "lime" means calcium oxide, CaO. Calcium oxide never occurs free in nature, but always in combination, either as a carbonate ($CaCO_3$) or even more commonly as a silicate. Further information about lime compounds appears under the heading of "Lime-bearing Minerals."

Magnesia.—Magnesia is the oxide of the light white metal magnesium, which is closely allied to calcium in many ways. A hydrated oxide of magnesia, known as brucite, occurs as a mineral, but is very rare. Magnesia usually appears in nature as a silicate, carbonate, or sulphate.

Carbonic Anhydride, or *Carbon Dioxide.*—The nature of carbon dioxide has already been explained. Besides being abundant in nature as carbonate, it is a small but important constituent of the atmosphere. Free carbon dioxide is given off by most or all volcanoes, and occurs in portions of the earth's crust, where it may be tapped by mining operations or by boring.

Moisture.—The moisture reported in rock-analyses generally means the water expelled by heating the powdered rock to 100° or 105° C. (212° or 221° F.). In the case where "moisture" and "organic matter" are reported together, water expelled at a higher temperature is included, as explained also below.

Organic Matter.—Limestone, being in most cases a rock of organic origin, may contain a little animal or vegetable matter which has not been wholly decomposed in the course of time. Sometimes mineral oil or bitumen in considerable quantity is present. As a rule, the true organic matter in most New Zealand limestones is negligible, and the term "water and organic matter" used in reporting the analysis means the loss of weight when the limestone is strongly heated, carbon dioxide excluded.

Loss on Ignition.—Loss on ignition includes all volatile or combustible substances driven off or burnt up when the powdered rock or other substance is strongly heated in air. In the case of a limestone it includes water (if not separately reported), organic matter, and carbon dioxide.

Phosphoric Anhydride.—The highly inflammable element phosphorus when burnt in air or oxygen forms a white powder, phosphoric anhydride or phosphorus pentoxide, P_2O_5. In nature this oxide, combined with metallic oxides to form phosphates, has a wide distribution. When it occurs in limestone it may be assumed to form the mineral phosphorite or collophane, which is calcium phosphate combined with a small proportion of calcium carbonate. More will be said about this very important though imperfectly known mineral in the chapter on phosphates (Part II).

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* Except that iron-rust contains more or less water.

Other Constituents. — Even the purest limestone contains at least traces of other substances besides those reported in an ordinary analysis made purely for agricultural purposes. The more important of these are usually potash, soda, and sulphur.

Potash, or potassium monoxide, K_2O, and *soda,* or sodium monoxide, Na_2O, occur combined in whatever silicates are present, particularly in feldspar and mica. *Sulphur* may occur as a sulphate—for example, calcium sulphate, $CaSO_4$—or as a sulphide. In the latter case it will probably be in the form of pyrite or iron bisulphide, FeS_2.

Nature of a Chemical Analysis.

A fairly complete chemical analysis of a limestone ought to show at least half a dozen other constituents besides carbon dioxide and calcium oxide or lime. The making of such an analysis requires from the chemist a high degree of technical knowledge and of skill in manipulating the apparatus employed. It is certain that some people are under the impression that the analysis even of a complex substance is a comparatively simple operation or series of operations, performed by the chemist in an hour or so. Such an impression would no doubt be heightened by seeing the rapidity with which a trained person can apply tests in order to determine the nature of a mineral or an unknown chemical salt. The name of " qualitative analysis " is sometimes applied to such tests, which are generally quickly performed with simple substances, but may involve a complicated and lengthy series of operations when the constituents of a complex compound or mixture such as the ordinary rock have to be determined. The word " analysis," however, used by itself means more than qualitative analysis. In practice it implies that the analysis is quantitative—that is, the various components of a substance, however complex, are separated from exactly weighed* portions of the substance, and themselves exactly weighed. As indicated on a former page, the results are then reduced to percentages.

The analysis of a limestone, which is not so complicated a piece of work as that of most other rocks, occupies many hours, and cannot well be made in less than two days. It is only by skilful organization, and by " running " a number of analyses more or less simultaneously, that the chemist is able to obtain results without a prohibitive expenditure of time. The fact that in this country an immense amount of unpaid analytical work has been performed by chemists attached to Government Departments, to University colleges, to Schools of Mines, and even by chemists practising privately, has helped to prevent the public as a whole from learning the debt it owes to the chemist, for the general tendency is to value unpaid work at cost price. In the long-run it would undoubtedly be far better for the common weal if all gratuitous scientific work should cease, and a fair charge be made for the services rendered. Such a system would reduce the unnecessary work (encouraged by free laboratories) to a minimum, and leave the scientist more lesiure for research, while at the same time providing him with a fair recompense for all work done on behalf of others.

LIME-BEARING MINERALS.

Carbonate of lime occurs in two distinct mineral forms, alike in chemical composition but physically different. These two forms are known to the mineralogist as calcite and aragonite. There may also be other forms of calcium carbonate.

Aragonite forms hard parts of reef-building corals, the shells of gasteropods, and the inner pearly layers of bivalve shells, but is otherwise a somewhat uncommon mineral of little importance as a source of lime.†

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* Under certain conditions liquids admit of measurement instead of weighing. Gases are usually measured by means of elaborate and complicated apparatus.

† Authoritative information concerning aragonite in organic structures is difficult to obtain, and it is somewhat doubtful how far it does or does not enter into the composition of shells, corals, &c.

Calcite, on the other hand, is a very abundant mineral, widely distributed through the earth's crust. There are numerous varieties, differing considerably in general appearance. All the varieties are characteristically of a light colour, but the presence of impurities may cause variations in tint from white or transparent to black. For the purposes of the present publication the chief forms in which carbonate of lime occurs may be enumerated and described as follows:—

(1.) Pure or nearly pure *calcite*, occurring in more or less perfect crystals, and then known as dog-tooth spar, nailhead spar, &c. Iceland spar is a perfectly transparent form.

(2.) Carbonate of lime, occurring in the form of *calcareous concretions*, which are usually very fine-grained and tough, but as a rule are not of great purity. Concretions are small masses of mineral substances which have collected round a nucleus. The nucleus may be a grain of some mineral other than that forming the mass of the concretion, a piece of vegetable matter, or it may be merely the point at which the concretion has begun to form. The late Alexander McKay's felicitous definition of a concretion may here be quoted: "A concretion is something that has gathered itself round about something else; sometimes there is nothing for it to gather about, but that does not prevent its being a concretion all the same, only there is no foreign substance in its heart."* Calcareous concretions occur in many forms—globular, ovoid, kidney-shaped, cylindrical, disk-like, dumb-bell shaped, or wholly irregular. They are common in claystone and the allied rocks, which in New Zealand are often called "papa." Calcareous concretionary bands or layers, usually very tough and impure, are not uncommon also in the calcareous claystones of this country.

(3.) *Massive limestone*, occurring in beds or layers. Such material forms the principal subject of this bulletin. Argillaceous or hydraulic limestone is an impure sub-variety, containing a considerable amount of clayey matter. As the clay increases, the rock grades into calcareous claystone. Arenaceous limestone is a limestone containing a considerable proportion of sandy matter. With an increase of the sand to, say, 50 per cent. arenaceous limestones become calcareous sandstones. Shelly limestone is a limestone composed very largely of visible fragments of shells. Some of the so-called shelly limestones of this country contain numerous pebbles, and are rather to be called shelly or calcareous conglomerates.

(4.) *Marble* is a highly crystallized altered limestone, suitable for ornamental use. The coarser-grained marbles are sometimes called crystalline limestones.

(5.) *Chalk* is a soft easily disintegrated variety of limestone, formed chiefly from the remains of the minute organisms known as Foraminifera.

(6.) *Coral-rock* is formed principally of the remains of corals.

(7.) *Calcareous marl* is a soft earthy deposit, formed chiefly in fresh-water lakes by the accumulation of the remains of calcareous algæ, fresh-water shells, &c. It grades into ordinary marl, which is simply a notably calcareous claystone.

(8.) *Stalactite* and *stalagmite* are materials formed in caves or under overhanging rocks by the deposition of carbonate of lime from water that has percolated through limestone or other calcareous rock. Moisture excluded, they are usually practically pure carbonate of lime.

(9.) *Calc-sinter*, *calcareous tufa* or *tuff*, and *travertine* are names applied to one and the same thing—namely, carbonate of lime deposited by springs or, more rarely, by streams.

(10.) In New Zealand *shells* form a somewhat important source of carbonate of lime. As a rule, they consist of almost pure calcium carbonate, either in the form of calcite or of aragonite. A few shells are highly phosphatic. The shells of crustacea are more phosphatic than those of ordinary shell-fish. As already indicated, corals, Bryozoa, Foraminifera, and some algæ are also important sources of carbonate of lime; and their remains, together with those of Mollusca (shell-fish), form the great bulk of the world's limestones.

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* "On the Prospects of finding Coal on Rowley's Farm, near Shag Point Railway-station." Rep. of Geol. Explor. during 1890–91, No. 21, 1892, p. 48.

Immense amounts of carbonate of lime exist in less pure forms than those enumerated above. If the percentage of carbonate of lime falls below 85 the limestone, as already explained, may be called "arenaceous" or "argillaceous," according to whether sand or clay is the chief impurity. Calcareous claystones, sandstones, and conglomerates are very common in New Zealand. The rock, or rather group of rocks, popularly called "papa" has a widespread distribution in both North and South Islands. Though in general only slightly or moderately calcareous, "papa" in places approaches or becomes argillaceous limestone. There are many rocks which, as first formed, contain lime only in the form of silicate, but by alteration come to contain several per cent. of carbonate of lime. In rare cases carbonate of lime in the form of calcite is an original constituent of igneous rocks.

Dolomite is a mineral composed of carbonate of lime and carbonate of magnesia, with possibly other carbonates. Typical dolomite, if pure, contains 54·35 per cent. of carbonate of lime and 45·65 per cent. of carbonate of magnesia. The union of the two substances s probably analogous to that of two metals in an alloy (especially such an alloy as Muntz metal) rather than to a strict chemical combination, such as that of calcium, carbon, and oxygen in carbonate of lime. It is not analogous to an ordinary mixture, because dolomite has a definite crystalline form and definite physical properties of its own. Dolomite forms the main constituent of extensive rock-masses in various parts of the world. Limestones with a moderate percentage of magnesia are not uncommon, and are termed dolomitic or magnesian limestones. Such rocks on microscopic examination are found to be mixtures of dolomite, calcite, and other minerals.

Various other minerals containing more or less carbonate of lime need not be mentioned here. There are, however, many minerals which contain a proportion of lime in the form not of carbonate, but of silicate. The chief of these are various varieties of feldspar, augite, and garnet. In addition there are two important mineral substances of which lime is one of the principal constituents. These are gypsum and phosphate of lime.

Gypsum is hydrated sulphate of lime, and is represented by the symbol $CaSO_4.2H_2O$. Varieties of it are known as satin-spar, alabaster, and selenite.

Several phosphates of lime, differing somewhat in chemical composition, and each having its own name, are known to the chemist. In ordinary usage the name "phosphate of lime" is applied to tricalcic calcium phosphate, with the symbol $Ca_3P_2O_8$. This substance does not occur pure in nature, but forms the essential constituent of the minerals apatite, phosphorite or collophane, and ordinary phosphate rock. It is also the most important constituent of green bones, and may be considered to form the whole of bone-ash, impurities excepted.

There are two varieties of apatite—*fluor-apatite*, with the composition represented by the compound symbol $3Ca_3P_2O_8 \cdot CaF_2$; and *chlor-apatite*, represented symbolically by $3Ca_3P_2O_8 \cdot CaCl_2$. "Phosphorite" and various other names have been applied to the form of phosphate of lime that forms the bulk of ordinary phosphate rock. Undoubtedly the mineral here present is an amorphous substance which has combined with it a small amount of carbonate of lime. Austin F. Rogers* proposes that the old name of "collophane" should be applied and restricted to this mineral. More information about this highly important substance (collophane) and other phosphate minerals will be found in Part II of this bulletin.

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* "A Review of the Amorphous Minerals." *Journal of Geology*, vol. 25, No. 6, Sept.–Oct., 1917, pp. 530 *et seq.*

TESTS FOR LIME AND LIMESTONE.

The simplest test for limestone or any other form of carbonate of lime consists in the application of any of the ordinary acids (in liquid form). If carbonate of lime is present numerous bubbles of gas will form. This gas is no other than the carbon dioxide (CO_2) already mentioned as the substance driven off from limestone by heating strongly.

The most satisfactory acids for general use are nitric acid (spirits of hartshorn) or hydrochloric acid (spirits of salt) diluted with one or two parts of water. Good vinegar will answer quite well. It is not generally known that various solid acids, such as tartaric and citric, can be used by placing a tiny pinch of the powdered material upon the stone together with a drop or two of water.

Ordinary limestone gives off gas quite freely when cold acid is applied, but fine-grained hard calcareous concretions, especially if magnesian, may effervesce very slowly unless powdered and gently heated. Dolomite is hardly affected by cold acids, but if it is powdered and gently heated brisk effervescence soon begins.

It will be observed that the acid test is for carbon dioxide rather than lime, but in practice this test, combined with the general appearance of the stone being tried, is quite sufficient. For full information regarding tests for lime and its various compounds the reader must be referred to works on chemistry and mineralogy, or to teachers of those subjects.

If a small piece of fairly pure limestone is placed in a glass or porcelain dish (say, an ordinary saucer) and covered with some acid in liquid form (preferably dilute nitric or hydrochloric) it will be seen that the fragment of stone as it effervesces diminishes in size, and after a short time breaks up and practically disappears, except that a little sand will be left in the dish or other vessel used. The effervescence ceases, the carbon dioxide of the limestone having now escaped, while the calcium oxide or lime formerly combined with it has united with the acid to form a new substance (calcium nitrate or chloride, according to the acid used), into the exact nature of which it is not necessary here to enter. A stone which, though it effervesces freely, does not break up when treated with acid is of poor quality, and is useless for the manufacture of quicklime.

The object of describing the above experiment is to show the reader how he may roughly ascertain the quality of a sample of limestone—namely, by comparing the residue after acid treatment with the original material. For this purpose the following directions may be given :—

Reduce what is considered an average sample of the limestone to a fine powder in any convenient way. The lumps may be broken into small pieces with a hammer on an anvil or on a hard flat stone, and then crushed to powder by placing them between two folds of brown paper and striking with the hammer. An iron pestle and mortar, if available, will, of course, be found much better than the brown paper and hammer. A very small sample may be powdered by pressure between two large coins. Take as much of the powdered limestone as will lie on a sixpence, place it in a saucer, dampen it with water, and then add a few drops of semi-dilute nitric or hydrochloric acid (one part of water by measure to one part of acid as bought from the chemist or drug-manufacturer). When effervescence ceases add two or three more drops of acid to make sure that all the carbonate of lime has dissolved, then gently pour off the acid or most of it, and compare the bulk of the sandy residue with that of the powdered limestone that may be conveniently placed on a sixpence. If there is clayey matter in the limestone the comparison will not be very satisfactory, because it will be impossible to decant the acid off the residue left after treatment without some loss. Should the residue, however, be sandy, and clearly less than one-tenth the bulk of the limestone taken for the test, then the limestone is of good quality.

If the powdered limestone taken for the test is weighed on a chemical balance, and the residue after acid treatment with aid of heat is transferred to a filter paper, washed with pure water, dried, collected (preferably after igniting—that is, strongly heating the material and burning the filter paper to an ash), and weighed, the difference of the two weights, due allowance being made for the ash of the filter paper when this has been ignited, represents with a moderate degree of accuracy the amount of carbonate of lime in the stone, plus any other carbonate, such as that of magnesia or iron, that may be present. The result thus obtained, however, is usually too high, because some of the silicates present will almost certainly have gone partly into solution. The weight of the residue left after acid treatment, reduced to a percentage of the weight of limestone taken, is the "insoluble" of some analyses (see p. 38).

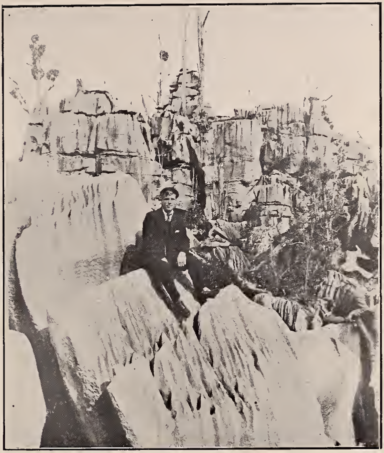
Geology of Limestone.

Limestone is a rock that during some bygone period of the earth's history was, as a rule, formed in beds or layers under a sheet of water, in most cases salt, but in some fresh. With the exceptions to this general statement the reader need not at present trouble himself. As originally formed most deposits of limestone extend over large and perhaps immense areas, but all, of course, must have had limits. Subsequent happenings have in nearly all cases reduced those limits, and not infrequently the reduction, especially for practical purposes, has been enormous.

In order that the reader may clearly understand what the original limits of a bed of limestone were he must ascertain the conditions accompanying the formation of the deposit—that is, its mode of origin; and if he would know what the present limits are he must not only explore the outcrops, but must study the changes that have taken place since the deposit was formed—that is, he must dip rather deeply into the science of geology.

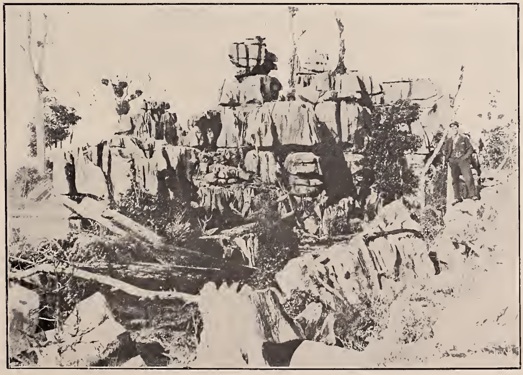
By proper field studies it will be found that some calcareous deposits—for example, those of concretionary origin, those formed by precipitation from springs (travertine), and those formed in fresh-water lakes—have comparatively small extent. Again, many limestone beds vary enormously in thickness and in quality from place to place. Often an originally large deposit, owing to the action of wind and weather, running water, ice, &c., becomes reduced to a small body. Especially is this the case when the limestone has been raised to an elevated position by forces working within the earth's crust, so that the eroding and dissolving agents mentioned above have free scope for action.

One of the most important facts in connection with carbonate of lime is that under certain conditions it is soluble in water, whilst under other conditions water containing carbonate of lime in solution deposits it as a solid substance (stalactite, stalagmite, travertine, &c.). Water is capable not only of dissolving many solids, but also of dissolving or absorbing appreciable quantities of all gases. Cold water in contact with carbon dioxide can dissolve its own bulk or more of the gas, and then becomes what may be called carbonated water. The solution is really a weak acid (the true carbonic acid), and, as such, slowly dissolves carbonate of lime and various other substances. If boiled it parts with its carbon dioxide, and the same thing happens to a considerable extent when the carbonated water is exposed to air. It is not the function of this bulletin to explain the physical laws regulating the solution of gases by liquids, and therefore the solution of carbon dioxide by water, but it is as well to say that scientific-



A. LIMESTONE, WARO, NEAR HIKURANGI, WHANGAREI COUNTY.
Note fluting or grooving of rocks in foreground caused by erosion.

[*Photo supplied by A. H. V. Morgan.*]



B. ANOTHER VIEW OF THE WARO ROCKS.

[*Photo supplied by A. H. V. Morgan.*]

ally exact statements cannot easily be made without diving into the science of physics. What has to be said here is that rain-water contains a little carbon dioxide derived from the atmosphere, and by means of this contained carbon dioxide it becomes capable of acting much more energetically upon limestone than perfectly pure water (which, it should be remembered, does dissolve limestone to a small extent). In its passage through the soil rain-water may absorb more carbon dioxide, produced by decaying vegetation, and thus become still more capable of dissolving carbonate of lime and many other minerals. Such comparatively highly carbonated water may percolate through limestone, slowly dissolving the rock in its journey. In the course of time great passages and caverns are thus formed in the limestone. Later the conditions are changed somewhat, and water dripping through the roofs of the caverns deposits part of its dissolved carbonate of lime in the form of stalactites pendent from the roofs, and the greater part of the remainder on the floors in the form of stalagmite. In this manner are formed the beautiful limestone caves found in many parts of the world. The explanation of stalactites and stalagmites generally given is twofold. In the first place, the lime-charged water holds more carbon dioxide in solution than it can normally take up from air. Coming into contact with air it gives up the excess of carbon dioxide, and then is compelled to deposit a corresponding amount of carbonate of lime hitherto held in solution as the double carbonate $CaCO_3.H_2CO_3$, otherwise represented as $CaH_2C_2O_6$. Secondly, some of the water evaporates, and with it some of the carbon dioxide goes. This causes precipitation of part of the dissolved carbonate of lime. It is possible that in some cases bacteria play a part in the formation of stalactites and stalagmites.

Large as may be the amount of carbonate of lime dissolved by carbonated water from limestone, a still larger amount is dissolved by percolating water from other classes of rock. Ultimately the greater part of this dissolved lime is carried by rivers to the sea, which is indeed the great storehouse from which nearly all limestone deposits are derived. From sea-water countless organisms, of which the most familiar are shell-fish and corals, abstract carbonate of lime in order to form their hard parts.* When these organisms die, their calcareous remains may be partly redissolved by the sea-water, but for the most part they collect on sea-beaches and on the sea-bottom, forming calcium-carbonate deposits of varying degrees of purity, which in time consolidate to hard limestone. As time goes on the calcareous deposits may be covered by beds of sand, mud, or other material. Then may come far-reaching geological changes: great earth-movements take place, the bed of the ocean is upheaved and becomes dry land. The originally horizontal or nearly horizontal strata may remain horizontal, but in many cases are tilted, broken by faults, and bent or crumpled into folds. In places the land may be so greatly elevated as to form mountain-ranges, on the top of which may be found rocks containing shells and other fossils, indicating that the strata once formed part of the ocean-bed. Unless the climatic conditions are altogether inhospitable vegetation quickly appears, forming a green protective coat on the newly born land. Running water and other erosive agents at once get to work, doing their best to destroy the work of the elevatory forces, and in course of time carve deep valleys. The limestone beds, which at first were probably hidden by overlying deposits, are exposed and dissected by the streams, which if small will follow underground channels in the limestone, but if large will soon cut valleys through it. An important practical point is the manner in which surface water and small streams disappear underground in limestone country owing to the formation of sinkholes and subterranean watercourses.

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* This statement has been disputed. Some authorities consider that dissolved calcium sulphate is the source of the lime used by sea-animals in building their solid parts. See A. Geikie's "Text-book of Geology," 4th ed., vol. 1, 1903, p. 613.

Emphasis must be given to the facts that all important limestone deposits have been formed in the sea as horizontal sheet-like layers of great lateral extent, and that subsequently they have been elevated, and in many cases contorted and broken. Denuding agencies have exposed beds of limestone originally hidden under other deposits, in places over wide areas, in places to a small extent only. In many districts the whole or the greater part of a limestone deposit has been removed by denudation.

Origin of Limestone.

Most limestone is of organic origin—that is, derived from the remains of calcareous animals or plants; some, however, is of chemical origin—that is, precipitated from solution; and some may be regarded as mechanically formed—that is, it is derived from the waste of a pre-existing calcareous deposit. Considered with respect to their origin or mode of formation, limestone deposits may therefore be divided into three classes, which will be described in the order of increasing importance.

I. *Mechanically formed Limestone.*—No limestone can be correctly termed a mechanically formed rock except with regard to its mode of accumulation. Thus limestone débris may collect at the foot of a cliff; shell-banks may be formed on a beach by the action of the waves; finely broken shells, corals, &c., may be blown inland by the wind and form calcareous sandhills and ridges. Some of the so-called soft-limestone deposits of New Zealand belong to this class. They seem to be weathered accumulations of limestone débris.

II. *Chemically formed Limestone.*—Carbonate of lime may possibly be precipitated from solution in shallow parts of the sea, owing to the heating or partial evaporation of the sea-water. Such deposits, however, if they occur, are of little importance. Even in the cases where arms of the sea have been totally cut off from it, and evaporated to dryness, no great bed of limestone can result. It is thought, however, that some large deposits of chalky limestone are partly of chemical origin. The theory is that in the deeper parts of a sea cut off from the general oceanic circulation chemical changes (assisted by bacteria) would cause the precipitation of carbonate of lime from sea-water.

The deposits of travertine, calcareous tufa, or calcareous sinter formed by precipitation of carbonate of lime from the water of some springs and a few rivers have already been mentioned. Calcareous sinter must be distinguished from the siliceous sinter deposited by most hot springs, a material which is valueless for agricultural purposes. There is reason to believe that much travertine has been formed through the action of fresh-water algæ, and thus is of organic and not chemical formation.

Oolitic limestone, or oolite—that is, limestone formed of small spherical grains of carbonate of lime with a concentric structure—is generally classed as of chemical origin, but it is now known that minute algæ play an important part in abstracting the carbonate of lime from sea-water, and therefore oolitic limestone is more correctly considered to be of organic origin. Pisolitic limestone, composed of large grains approaching peas in size, is otherwise similar to oolite.

At Kotuku, near Greymouth, several bores drilled in search of oil discharge in geyser-like fashion salt water highly charged with carbon dioxide and dissolved carbonate of lime. The greater part of the carbon dioxide at once escapes, and abundant carbonate of lime is in consequence deposited wherever the water touches any solid object. As the water flows away it forms numerous little balls of carbonate of lime, in size and appearance resembling marbles. Here, at least, we have chemically formed "pisolite."

Under the head of chemically formed limestone are to be included stalactite, stalagmite, and calcareous concretions of all kinds. Veins of calcite such as are common in the rocks of many districts—for example, the Waihi goldfield—may be classed here.

Marble, or limestone that has been more or less recrystallized and otherwise altered, is sometimes classed as a chemically formed rock. For most purposes it is better to go farther back in its history and consider the mode of formation of the original limestone.

III. *Organically formed Limestone.* — This, the most important class of limestone, includes all limestones formed by the action of plants or animals. The chief of these are: Ordinary limestone, formed by the accumulation of calcareous material secreted by living organisms of many kinds; coral limestone, in which the main part of the material is composed of the hard parts of corals; polyzoan limestone, similar to coral limestone, but composed mainly of the remains of Polyzoa (Bryozoa); chalk, composed mainly of the remains of the minute organisms known as Foraminifera; alga limestone, formed mainly of the remains of calcareous algæ; and lake-marl, formed in lakes by the accumulation of the remains of fresh-water algæ, shells, and other organisms.

The following part analysis* of a calcareous seaweed or alga (*Iania novæ-zelandiæ*) is of interest, and is therefore quoted here: Water and organic matter, 31·8 per cent. (containing nitrogen 0·35 per cent.); calcium carbonate, 50 per cent.; potash and phosphoric acid, traces.

Altered and Metamorphic Limestones.

Very often, owing to solution and re-precipitation of carbonate of lime by percolating water, the appearance of a limestone is so changed that its original character may be a matter of doubt. Such altered limestones usually exhibit what is known as a crystalline structure. Many limestones, especially those in the older rock formations, have been converted into the highly crystalline form known as marble by the combined action of water, heat, and pressure.

Some limestones, especially those that originally were somewhat impure, are found to contain great numbers of siliceous concretions. The flint nodules of chalk deposits are of this character. Again, a limestone, by the infiltration of water containing silica in solution, may be almost wholly changed to chert, a flinty form of silica or quartz. In this case most of the carbonate of lime has been removed in solution, and silica brought by the dissolving waters has taken its place.

When igneous rocks such as granite or diorite are intruded into limestone great changes may take place near the intrusive rock. The carbon dioxide of the limestone is largely expelled; and highly heated siliceous waters escaping from or associated with the igneous rock convert the lime into various silicate minerals, the chief of which are garnet, wollastonite, vesuvianite, diopside, and epidote.

Mode of Occurrence of Limestone.

The mode of occurrence of limestone has been more or less indicated on the preceding pages. In recapitulation it may be said that limestone occurs typically in widespread beds or sheets of variable thickness, enclosed in other sedimentary strata. Subsequently to their formation these strata have been upheaved, tilted, folded, broken, and subjected to denudation. Hence the limestone, once a continuous horizontal sheet, may be found in all kinds of positions, even in that of verticality. In some places large amounts of limestone may be exposed; in others either the amount of limestone is actually small, or the greater part is deeply buried beneath superincumbent strata. In such a case, if the structure and thickness of the enclosing strata are observed, it is possible to ascertain the depth of the limestone stratum at any given point. The mode of occurrence of non-stratified deposits of limestone, such as stalagmite, stalactite, travertine, slope débris (talus), calcite veins, &c., is sufficiently explained by their mode of formation.

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* Aston, B. C.: 10th Ann. Rep. Dept. Agric., Chemical Division, 1902, p. 119.

Geological Systems and the Geological Time-scale.

The study of the sedimentary strata covering the earth's surface shows that in the aggregate they are of great thickness, and that their deposition has occupied a long period of time, probably quite 100,000,000 years.* The non-geological reader may perhaps need to be reminded that once none of the rocks he sees around him were in existence. This applies to the igneous rocks now exposed on the earth's surface, as well as to the sedimentary rocks; but this bulletin is concerned only with the latter, except in the case of the so-called marble of Milford Sound, and possibly one or two other localities in western Otago, where masses of carbonate have been formed by some unexplained process in connection with igneous rocks.

The older sedimentary rocks are, of course, overlain by the younger, except where great earth-movements causing compression of the strata or complicated faulting have caused overturning, an occurrence that is only local, and is usually easily detected. Although, owing to elevation above sea-level alternating with depression, and owing to erosion during periods when the land emerged from the sea, the succession of strata is in no locality complete, nor can a complete record be obtained even by piecing together the data obtained in different localities, yet geologists, largely through the aid of fossils, have obtained a good, though imperfect, understanding of the past history of the earth. The sedimentary rocks have been placed according to age in several great divisions, known as the Palæozoic (at one time called Primary), Mesozoic (Secondary), and Cainozoic (or Tertiary) eras. The rocks formed during and since the time known as the glacial epoch, a time when ice invaded the lowlands of much of Europe and of the northern part of North America, are placed in the Quaternary era or age. The rocks of each era are classified, according to principles explained in works on geology, into systems each corresponding to a period of time, and these are subdivided into series, formations, and stages, the last-named subdivision representing what are called epochs of time.† The breaks in deposition caused by recurring elevation of the sea-bottom, or rather of portions of it, above sea-level are considered by all stratigraphical geologists of prime importance in delimiting the geological systems.‡ During times of depression the loss of material caused by erosion during elevation was made good by the deposition of new strata. A little reflection will show that these matters are of importance to the inhabitants of the earth. To take an illustration that directly concerns the subject of this bulletin: during periods of depression limestone deposits were formed, whilst elevation brought them within reach of man and has also led to their part loss through erosion.

It is known that the geological history of all parts of the earth's surface has not been the same. Local elevation and depression on a small scale has often happened without other parts of the earth, so far as known, being affected. On the other hand, it is believed that the major movements have been world-wide, and have produced results that can be traced on all parts of the earth's surface by one means or another. Hence geological systems established by study on one par of the earth's surface are thought to be applicable to other parts; but in many cases it is impracticable to trace the subdivisions of the systems made in Europe through the rocks of another continent or far-distant islands like those of New Zealand. Indeed, were it not for fossils, little could be done in correlating the rocks of one country with those of another, and almost the whole science of stratigraphical geology would be undone. Parenthetically it may be said that fossils are of tremendous importance not only to the science of geology, but also to that of evolutionary biology.

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* Estimates of the period in question vary from a few million years to 700,000,000 years or more. The lower estimates cannot possibly be accepted, the higher are more than doubtful. The earth itself, however, was formed long before the oldest known sedimentary rocks. From a geological point of view it would be reasonable to suppose its total age to be roughly 200,000,000 years.

† Some authors use "age" as the time-term corresponding to "stage." Geological usage of these and similar terms is by no means uniform. See Arch. Geikie: "A Text-book of Geology," vol. 2, p. 859, 4th ed., 1903.

‡ This statement will not be fully endorsed by all geologists, but the exceptions will be found mainly among those who pay great attention to theoretical considerations, or who have not had much to do with stratigraphical geology.

On account of the difficulty of correlation, local names are frequently used for geological formations and even systems, and the proposal has been made that in New Zealand the attempt to use the European time-scale should be practically abandoned. Though the use of a local set of system-names as an alternative to the European names is convenient and commendable, the European time-scale ought never to be lost sight of. Opinion, however, is bound to differ as to what amount of prominence should be given to it.*

The following table illustrates the various geological systems represented in New Zealand:—

Era or Age.	System or Period. (European Time-scale.)	Corresponding New Zealand System.
Quaternary	Recent	Recent.
	Pleistocene	Pleistocene.
	Pliocene	Wanganui.
Cainozoic or Tertiary ..	Miocene Oligocene	Oamaru.
	Eocene	Mawheranui or Waimangaroa.
	Cretaceous	Waipara.
Mesozoic	Jurassic Triassic	Trias-Jura (Hokonui system of Park).
	Permian Carboniferous ..	Maitai.
	Devonian	Te Anau (?).
Palæozoic	Silurian	Baton River. Part of Aorere (?).
	Ordovician	Aorere.
	Cambrian	Part of Aorere (?). Maniototo Series of Park (?).
Archæan (=pre-Palæozoic)	Various divisions ..	Manapouri (?).

By consulting the classifications given by Park† and Marshall‡ the reader will ascertain that unfortunately there are still great divergences of opinion among New Zealand geologists concerning the classification of the sedimentary strata.

A table of geological systems like that given above is a time-scale as well as a rock-classification. The periods represented are, however, of very unequal lengths. Though in general geologists avoid stating ages in years, for the excellent reason that they are unable definitely to fix the length of any given geological period, yet estimates based on assumptions of one kind or another have been made. Various authorities consider that the Palæozoic periods were from 40,000,000 or 50,000,000 to 100,000,000 years or more ago; and the Mesozoic periods from, say, 8,000,000 to perhaps 40,000,000 years ago; whilst the Tertiary periods reach back less than 7,000,000 years. The Eocene may have begun 5,000,000 or 6,000,000 years ago, the Miocene 3,000,000 years ago or less. Pleistocene time is comprised within the last 200,000 years, and Recent time within the last 30,000 or 40,000 years.

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* A good statement of the case, but summing up against the European time-scale, will be found in P. Marshall's "Geology of New Zealand," 1912, pp. 173–74.

† Park, James: "The Geology of New Zealand," 1910, p. 25.

‡ Marshall, Patrick: "Geology of New Zealand," 1912, p. 173.

At one time physicists wished to restrict the age of the earth, as reckoned from the beginning of life on its surface, to 25,000,000 or 30,000,000 years. The chief reason given was that the sun could not have poured out heat for a longer period. The discovery of radium has changed all that; and now some physicists, as the result of studies on the radio-activity of rocks, assign most extravagant ages to them, such as 1,000,000,000 years and more. Some biologists and palæontologists, on evolutionary grounds, demand at least 400,000,000 years for the development of life on the earth to its present stage, but most geologists are satisfied with the 100,000,000 years mentioned above.

In New Zealand probably more limestone is of Miocene age than any other, but Pliocene, Cretaceous, and Ordovician limestones are also abundant.

Definitions of some Geological Terms.

On many pages of this book geological terms are necessarily used, and for the convenience of non-technical readers who have no standard dictionary or text-book at hand a few definitions of the more important are here given.

Sedimentary Rocks.—Those rocks which consist of accumulations of material derived from previously existing rocks or of organic remains. Most sedimentary rocks have been formed by the action of moving water, and in general have accumulated in the sea or in lakes, but some—for example, river-gravels—have been formed on a land surface. Æolian or wind-formed rocks, such as the sand of sandhills, constitute another class of sedimentary rocks that has also been formed on the surface of the land.

Igneous Rocks are those rocks which have once been in a molten condition, and have either consolidated in the crust of the earth (plutonic rocks) or on the surface (lavas or volcanic rocks).

Stratification or *Bedding.*—Sedimentary rocks generally show distinctly that they are formed of a number of layers, one superimposed on another, like the leaves of a book. Each distinct layer forms a bed or stratum (plural, "strata"). The terms "bed" and "stratum" are very often extended in meaning to include the whole mass of one kind of rock, particularly when the parting-planes between the various layers are not very distinct. "Stratification" and "bedding" are abstract nouns referring to the arrangement of rocks in strata. We speak of "horizontal stratification" when the beds lie level, "inclined stratification" when the beds are tilted or folded, and so on.

Strike.—Strike is a horizontal line drawn in an inclined bed or on a fault-plane, or it may be defined as the line of outcrop on a perfectly level surface. In practice the word "strike" generally means the direction of the horizontal line as defined above, as measured at some particular point, but it is no doubt more exact to speak of the direction of the strike.

Dip.—Dip is the inclination of a bed or fault-surface, &c., from the horizontal. The term is generally used so as to mean direction of inclination from the horizontal. The direction of dip of a stratum is always at right angles to the strike-direction.

At the end of Part II of this bulletin will be found a glossary of all technical terms used in it.

SAMPLING LIMESTONE.

The operation of sampling a substance with a view to making an analysis is most important, for if the sample is not properly taken the analyst's skill and time will be wholly or largely wasted. The complete analysis of a rock takes days of the chemist's time; it is therefore irrational, in most cases at least, to spend only minutes in taking the sample. The sampling of an agricultural limestone need not be so elaborate as when the stone is to be used in the manufacture of glass or in certain other chemical industries, but it will be admitted that the more carefully the work is done the better. Hitherto in New Zealand the samples of limestone and of many other substances collected in the field have consisted of single lumps (which may be called fortuitous or "grab" samples), or of a few pieces of stone broken here and there from the deposit, so as to form as representative a sample as the collector knew how to obtain under the particular circumstances. Such samples may be termed "empirical" samples, and represent most of the samples collected by the Geological Survey in the course of its ordinary work.

Concerning the types of samples termed above "grab" and "empirical," Orton and Peppel write: "Experiment has shown that it is difficult, if not impossible, for any person to select a sample without bias, even where not interested in the result, if he is acquainted with the effect of his actions in putting in or rejecting portions."* This statement is somewhat unhappily worded, for it may be construed to imply that the less a person knows, the more likely he is to select a true sample; nor does it differentiate between the grab sample and the empirical. The meaning, however, is this: An interested person—for example, a prospector—is hardly able to resist the temptation of putting a large proportion of the best-looking material in his sample, instead of selecting average-looking material. Some men, perhaps with the best intentions, select nothing but the best material, and then persuade themselves that they have collected average samples. On the other hand, a person with a judicial temperament, if possessed of the requisite technical knowledge, and keenly interested in obtaining a true average sample — for example, a mine-manager or a battery-superintendent—may be trusted to select samples that on the whole will yield an average result, with possibly a slight error one way or the other, due to the personal equation.

The sampling of limestone and other nearly homogeneous substances does not present the same difficulty as the sampling of variable material such as auriferous quartz. In the case of limestone to be used for agricultural purposes only, the method of collecting empirical samples by chipping off average-looking fragments with hammer and chisel will give good results in the hands of an experienced person; and even an inexperienced person, by taking pains, employing common-sense, and resisting the temptation to select the best material, ought to obtain fairly representative samples. In this method of sampling the following points have to be observed:—

(1.) In the case of an unworked limestone deposit the places to be sampled ought to be selected with a view to access and convenience of working.

(2.) The limestone outcrop ought to be carefully observed, with a view to determining whether it is fairly uniform in quality from top to bottom.

(3.) If the limestone stratum is thick, and especially if the different layers show want of uniformity, it must be divided into sections of measured thickness.

(4.) The material to form the sample ought to be selected along lines at right angles to the plane of the deposit—that is, along lines that measure the thickness. Such lines will be at right angles both to strike and dip. It is true the latter condition need not be exactly fulfilled, but the nearer one can approach to it the better.

(5.) In sampling the various sections care must be taken to select a proper proportion of each kind of material, as nearly as can be judged by the eye. Thus if the stone is partly hard and partly soft a due proportion of hard rock must be selected. If there are argillaceous, arenaceous, or greensandy layers present, a fair amount of the impure material must be taken. The inexperienced or non-judicial sampler is very apt to neglect this point.

(6.) If the outcrop is large, samples should be selected along several lines, duly divided into such sections as necessary, and spaced at equal distances from one another.

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* Orton, Edward, and Peppel, S. V.: "The Limestone Resources and the Lime Industry in Ohio." Geol. Surv. of Ohio, 4th Series, Bull. No. 4, 1906, p. 26.

(7.) Careful notes concerning the locality of each sample, and the thickness and class of stone it represents, should be taken.

(8.) Each sample should be carefully labelled, and placed with its label in a stout canvas bag, which also should be labelled or numbered.

(9.) The analyst should be given full particulars concerning the locality of the deposit, and such other information as may seem desirable or be asked for. Do not send him single lumps of stone or carelessly selected samples. Do not be so foolish as to attempt to mislead him as to he locality or nature of the deposit. Those who misinform or deceive the analyst are bound to be the losers in the long-run.

Quartering down.—In general a sample of limestone if properly taken will be too large to send by parcel-post to the analyst. It can safely be reduced in size by the method of quartering down. This consists in breaking all large pieces of stone to a small size—say, that of hazel-nuts or smaller—mixing the sample well, and piling it on a flat smooth surface in a somewhat low conical heap, which is then carefully spread out in a circle. The material is then divided into four quarters by drawing two narrow channels at right angles through the centre of the material. Two opposite quarters are then removed, and the operations of mixing, piling, spreading out, and quartering repeated. If a small sample is desired the lumps must be broken still smaller before quartering is repeated. The best procedure of all is to reduce the whole sample to a coarse powder before quartering down, but in the field this is not practicable.

Quartering down may also be employed where duplicate samples are required. The method of obtaining supposed duplicates by breaking a single lump in half, or of dividing a rough sample in two by picking out a few lumps, need only be mentioned to be condemned; yet there are frequent cases where persons have used this method, and have been surprised when the analyses of the two samples did not agree. Quite commonly the analyst is blamed for his lack of skill. If two analysts have been employed, the one who gets the lower results will get the credit of being unskilful or ignorant. As a matter of fact, an inexperienced sampler will obtain concordant duplicate samples only by accident.

Quarry sampling.—Where a quarry has been opened the facilities for sampling are generally better than in the case of ordinary outcrops. If only one or two general samples are desired the broken rock may be sampled, but usually it is better to sample the rock-faces in sections, as described above. When a rock-breaker is at work it is feasible to obtain a good average sample from the material passing through the machine, care being taken to select proper proportions of coarse and fine. The sample, which should be large and selected at intervals, may then be broken and quartered down as described. If a fine-grinding machine forms part of the equipment, as in a limestone-pulverizing plant or cement-mill, no difficulty need be experienced in getting good average samples.

Systematic sampling.—The ideal method of securing true samples of a hard deposit is to bore it from top to bottom with a diamond drill, and save all the core. If the deposit is soft it may be bored in some other way, and all the drillings saved for analysis. Alternating hard and soft layers will prevent thoroughly representative samples of the whole being obtained by drilling-methods. The usual method of sampling an exposed face of rock or mineral is to cut a uniform groove from top to bottom, and save all the cuttings. The face, if high, and especially if heterogeneous in composition, is divided into sections. An experienced sampler will alter his methods according to circumstances; but the following details, mainly quoted or paraphrased from Orton and Peppel,* illustrate the general methods of systematically sampling an outcrop or quarry-face :—

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* Orton, Edward, and Peppel, S. V.: *loc. cit.*, pp. 27–28.

(1.) The sample should be cut from the strata in place rather than taken from the stock pile of the quarry. The latter is liable to fluctuate from hour to hour, as the product of one stratum or horizon happens to form its surface layer, as may be the case after a large shot is fired. Very often it is not possible to tell whether the pile of débris at the foot of the face is representative of the whole face or not.

(2.) The part to be cut should be first well cleaned from top to bottom by sweeping with a broom or brush.

(3.) A large canvas sheet (one 9 ft. square was used by Orton and Peppel) should be spread close under the place selected, so that the cuttings will fall and be collected on the sheet.

(4.) A groove, uniform in width (2 in. or 3 in.) and in depth (1 in., 2 in., or 3 in.), should be cut from top to bottom of the face to be sampled. The tools used may consist of a blacksmith's hammer of about 4 lb. weight, one or two cold-chisels mounted on handles, and a few heavy stone-cutters, gads, &c. It is desirable that the groove should be cut in a straight line from top to bottom of the section sampled; but if this is impracticable, then by following the edges of bedding-planes, and collecting from different strata in one small area, a full cross-section of the limestone may be obtained. When on account of the nature of the rock being sampled, or its location at great height requiring climbing and working with scant footing, a groove cannot be cut, the canvas may be removed from the foot of the face and large lumps of rock broken out of the various layers. From each of these a section of the proper size may be dressed.

Where narrow strips of shale, greensand, or other impurity occur, these should be carefully cut to the proper section, and all the cut material allowed to drop on the sampling-sheet. If the impure bands are wide it is better in some cases to sample them separately. The width, of course, must be carefully measured.

(5.) All the cuttings should be saved on the sheet, but pieces of stone known to be accidentally dislodged from points adjacent to the groove should be rejected.

(6.) The total weight of the sample may range from 5 lb. to 150 lb. In special cases it may be greater. Apparently Orton and Peppel, as a rule, took only one sample of a high quarry-face. It would be better in many cases to divide the face into measured sections and take several samples.

(7.) Every sample should be labelled plainly and legibly with a number and other particulars inside and outside of the sack in which it is placed. The inside number may be written or cut on a piece of soft wood and then wrapped in cloth. Whatever the method, care should be taken that the marking cannot be obliterated or the label lost.

(8.) If the sample is taken from a stock pile, bins, rock-breaker, or any unusual source, all the circumstances should be noted.

(9.) Every detail of the sampling and every observation of the material sampled should be noted at the time the sample is taken. The entries in the notebook used should be clearly worded and legibly written. Abbreviations should be sparingly used.

Orton and Peppel give further details, which need not be quoted, of how the main sample, by crushing and quartering, is reduced to the small sample of about $\frac{1}{2}$ lb. weight used by the analyst for his work.

As previously stated, for agricultural purposes limestone need not be sampled in quite so elaborate a manner as that just described, but for some industries sampling of that kind is very necessary. In reconnaissance work and in general geological survey it is usually impracticable to take samples by the method of cutting a continuous groove. Provided the geologist or other explorer has experience, skill, and a knowledge of the general principles of sampling, he can without much difficulty select empirical samples that are representative of the locality sampled; but during the preliminary examinations it is generally not feasible to take all the samples that may be required for a thorough knowledge of the deposit, the expense and time involved in such work being usually prohibitive. It may be added that where a deposit is being worked on a large scale, and small variations in quality do not matter, numerous empirical samples may safely take the place of a smaller number of systematic samples.

LITERATURE.

The literature consulted in the preparation of this bulletin may be divided into two sections: (1) New Zealand publications read in order to obtain information concerning outcrops or analyses of limestone, and (2) publications, mostly foreign, read in order to obtain general information and hints as to treatment of the subject. The chief New Zealand publications consulted for information *re* limestone occurrences are the Reports of Geological Explorations, Nos. 1 to 22, issued by the New Zealand Geological Survey under Sir James Hector; geological reports by Alex. McKay and others, contained as parliamentary papers in the Mines Reports from 1892 to 1901; the bulletins (Nos. 1 to 20) and annual reports of the Geological Survey from 1906 onwards; the "Transactions of the New Zealand Institute" since 1869 (vols. 1 to 50); Hochstetter's "New Zealand" (English translation, 1867); Hutton and Ulrich's "Geology of Otago" (1875); von Haast's "Geology of Canterbury and Westland," &c. In Chapters III and IV under each county heading abbreviated lists of literature are generally given, which it is hoped will enable those interested to consult the chief publications having reference to the limestone or geology of the county. The methods of citation and reference employed are not quite uniform throughout, but it is thought that no difficulty will arise from any variation in this respect. As a rule, though for one reason and another trivial references may be given, no attempt to make the list of publications complete for each county has been made. This course would have wearied the ordinary reader to no purpose, and would have involved much overlapping and repetition, for one and the same report may deal with half a dozen or more counties. In some cases the list of publications is cut short and the reader referred to a geological bulletin for further information.

An attempt has been made to compile, and in most cases to quote, all official published analyses of limestone. The annual reports of the Colonial Museum and Laboratory, later of the Colonial Laboratory, and still later of the Dominion Laboratory, form a continuous series from No. 1 (1869) to No. 50 (1917), and have been found a rich mine of information. The other chief sources of information have been the annual reports of the Chief Chemist of the Agricultural Department (Mr. B. C. Aston), but not all of these were available at the time the various sections were written, and on this account references are generally made only to Mr. Aston's lists in the September and October numbers of the *Journal of Agriculture*, vol. 11, 1915.

Various unpublished analyses made in the Dominion Laboratory for the Geological Survey have been cited, and a few analyses by the late Dr. J. G. Black and others have been included. It is a matter for regret that "Reports and Awards of the Jurors" (with Appendices), "New Zealand Exhibition, 1865," published in 1866, was not available until the writing of this bulletin had been nearly finished. This contains forty-two analyses of limestones and other calcareous rocks, which are quoted or mentioned in an appendix to Chapter III, but, with a few exceptions, have not been interpolated under the county headings. The publication mentioned contains some very valuable matter, which ought not to be lost sight of by those interested in the geology and mineralogy of New Zealand.

The general literature consulted in writing Chapters I to IV of this bulletin is listed below. The publications read in connection with the phosphate resources of the Dominion are mentioned at the end of Chapter V.* A list of references to limestone, lime, &c., found in the *Journal of Agriculture* from vol. 1, June–Dec., 1910, to the end of vol. 16, Jan.–June, 1918, follows the list of general literature.

1900. Sherzer, W. H.: "Geological Report on Monroe County, Michigan." Geol. Surv. of Michigan, vol. 7, part 1. Pages 175–83 deal with lime, limestone, &c.

1906. Orton, Edward, and Peppel, S. V.: "The Limestone Resources and the Lime Industry in Ohio." Geol. Surv. of Ohio, 4th Series, Bull. No. 4.

1907. Bain, H. Foster, and Others: "Year-book for 1906." Illinois State Geol. Surv. Bull. No. 4. Pages 177–83 (by F. B. van Horn) deal with "Limestones available for Fertilizers."

1907 (date of letter of transmittal). Buehler, H. A.: "The Lime and Cement Resources of Missouri." Missouri Bureau of Geology and Mines, vol. 6, 2nd Series.

1909. Maryland Geological Survey, vol. 8. Pages 138–44 (by William Bullock Clark and Edward B. Matthews) deal with "Lime and Cement."

1912. Bleininger, A. V.; Lines, E. F.; and Layman, F. E.: "Portland-cement Resources of Illinois." Ill. State Geol. Surv. Bull. No. 17.

1917. Loughlin, G. F.: "Limestone and Lime." U.S. Geol. Surv. Bull. 666 R, part of Bull. No. 666 ("Our Mineral Supplies").

The following volumes of *The Mineral Industry*, the well-known compilation published in New York yearly since 1893, have been consulted:—

1894. Vol. 2 (for 1893), pp. 443–52 ("Limestone, Marble, and Lime").

1902. Vol. 7 (for 1899), pp. 477–96 ("Limestone, Lime, and Lime-burning").

1906. Vol. 14 (for 1905), pp. 428–29 ("Limestone").

1907. Vol. 15 (for 1906), pp. 551–52 ("Limestone").

1908. Vol. 16 (for 1907), pp. 694–96 ("Limestone").

The articles on "Cement" have also been consulted.

In connection with pulverizing machinery, described in Chapter IV (Part II), the chief sources of information have been various works on the metallurgy of gold-ores, &c., supplemented by manuscript notes made by P. G. Morgan many years ago, maker's catalogues, &c.

Some well-known works on agriculture have been consulted to a small extent, but these need hardly be listed here. The only articles in the "Transactions of the New Zealand Institute" that deal with lime or limestone from an agricultural point of view are the following:—

Hay, D.: "Lime as a Manure: Its Beneficial Effects when applied to the Cultivation of the Soil." Vol. 9, 1877, pp. 206–9.

Wild, L. J., and Anderson, J. G.: "On the Absorption of Lime by Soils: An Investigation of the Hutchinson-McLennan Method of determining the Lime Requirements of Soils." Vol. 50, 1918, pp. 466–75.

The Transactions, however, contain many references to limestone, the more important of which are given in Chapters II and III as occasion arises.

The following references to lime, limestone, &c., occur in the New Zealand *Journal of Agriculture*:—

Vol. 1 (June–December, 1910).—p. 17: Lime recommended for Mackenzie Plain. pp. 22 *et seq.*: Lime recommended for pakihi soils (Westport district, &c.); pot experiments (Aston). p. 100: Lime-salt-sulphur wash. pp. 122–24: Lime, &c.,

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* Chapters IV and V form Part II of this bulletin, which will be published separately.

for Pahiatua pasture-land. pp. 197–98: Experiments with ground lime and limestone at Ruakura. pp. 200, 201, 202: Experiments with lime, &c., at Moumahaki. p. 307: Lime, &c., for pumice land. p. 353: Ground limestone for lucerne crop, Moumahaki (see also vol. 2, pp. 191–93). pp. 410, 411, &c.: Experiments with lime for turnips.

Vol. 2 (January–June, 1911).—pp. 16, 17: Calcareous sand, Enderby Island, Auckland Group (B. C. Aston). p. 162: Liming pakihi land near Westport. pp. 191 *et seq.*: Ground limestone for lucerne crop, Moumahaki. p. 364: Liming reclaimed swamp land, Ruakura.

Vol. 3. (July–December, 1911).—p. 162: Lime for wheat land. p. 163: Best form in which to apply lime to land, &c.; value of lime. p. 264: Lime for pea crop. p. 474: Lime, &c., for pea crop on "gum" land (Kumeu North). p. 527: Application of "shell" lime.

Vol. 4 (January–June, 1912).—p. 11: Carbonate of lime used at Marton. pp. 323–24: Advice *re* using "burnt" lime and carbonate of lime. p. 518: Limestone used experimentally at Kumeu. p. 536: Advice *re* liming rushy land.

Vol. 5 (July–December, 1912).—p. 15: Lime in milk. pp. 71–74: Treatment of refractory soils near Onekaka, Nelson, &c.; lime, ground limestone, &c., used experimentally (G. de S. Baylis) (see also p. 116). p. 90: Question *re* stored "lime" answered; note that the word "lime" is not defined by the correspondent, and he gets a non-committal answer, which probably leaves him no wiser than he was before. p. 340: Liming Southland land. p. 564: Effect of mixing lime with superphosphate (see also vol. 6, p. 355). p. 567: "Burnt" lime recommended for clay soils. p. 687: Recipe for "lighthouse" limewash.

Vol. 6 (January–June, 1913).—pp. 75, 408: Lime-sulphur solution as a summer spray (see also vol. 9, pp. 274–77, preparation of solution). p. 121: Lime in lucerne cultivation (see also vol. 7, p. 101). p. 256: Effect of mixing lime with basic slag (no loss) and bonedust (ammonia lost). p. 289: Lime as an insecticide. p. 305: Effect of lime and sulphur as a manure. p. 355: Effect of mixing lime with superphosphate. p. 560: Lime is said to assist in destroying sorrel (see also vol. 7, pp. 347–48, 591–94; vol. 9, p. 66, &c.). p. 564: Lime should not be used with liquid or solid manure.

Vol. 7 (July–December, 1913).—p. 3: Nitrate of lime. p. 101: Lime in lucerne-cultivation. p. 105: Agricultural lime, Te Kuiti. pp. 116–18: Influence of lime; cheaper lime wanted (B. C. Aston). p. 170: Apply lime and phosphate to Canterbury scrub land. pp. 295–300: Lime, phosphate, &c., for pakihi lands (Aston) (see also p. 391). pp. 347–48: Liming sorrel-infested land. p. 391: Liming pakihi land. pp. 591–94: Liming sorrel-infested land, &c. (Aston) (see also pp. 347–48).

Vol. 8 (January–June, 1914).—pp. 47–48: Lime experiments at Ruakura (Primrose McConnell). pp. 388–91: Ground limestone, its value on New Zealand soils (B. C. Aston). pp. 391–93: Machinery for grinding limestone (illustrated). pp. 566, 572: Lime in and lime for Hauraki Plains soil (Aston). p. 615: A spreader for lime (illustrated) (see also vol. 9, p. 34).

Vol. 9 (July–December, 1914).—p. 34: Machine for sowing lime and fertilizers (illustrated). p. 66: Lime and gas-lime for eradicating sorrel. p. 118: Lime from acetylene generators. p. 179: Lime used at Ruakura for soil-dressing. p. 220: Pakihi land should be drained, limed, and ploughed. pp. 274–77: Preparation and storing of lime-sulphur wash. p. 328: Cheap limestone from Mauriceville (see also vol. 8, p. 390).

Vol. 10 (January–June, 1915).—pp. 86–87 : Giraffe brand lime-sulphur spray p. 577 : Application of "burnt" lime and carbonate of lime with oats, turnip-seed, &c.

Vol. 11 (July–December, 1915).—pp. 111–15 : Phosphates and limestone (B. C. Aston); ground limestone in bulk (pp. 114–15). pp. 235–40 : Analyses of North Island limestones (Aston) (see also p. 410). pp. 243–47 : Lime-sulphur spray (see also previous volumes). pp. 328–32 : Analyses of South Island limestones (Aston). pp. 393–94 : Limestone development in Canterbury (Aston). pp. 394–400 : Soil survey operations and limestone finds in Canterbury (A. McTaggart). pp. 403–10 : Limestone in Wairarapa and Manawatu Gorge districts (Aston) (describes deposits at or near Manawatu, Ngawapurua (south of Woodville), Pahiatua and Makuri Gorge, Mauriceville, Pirinoa, &c.; twenty-one analyses are quoted). p. 528 : Use ground "burnt" lime for swamp soils.

Vol. 12 (January–June, 1916).—pp. 10–12 : Soft limestone on "gum" lands (B. C. Aston) (see also p. 329). pp. 47–54 : Lime and magnesia in New Zealand soils (Aston). pp. 77–78 : Do not give precipitated chalk to pigs. pp. 303–4 : Papa rock as a soil-dressing (G. de S. Baylis). p. 329 : Application of lime or ground limestone to "gum" land. pp. 339–56 : Principles and practice of liming (A. McTaggart) (illustrations show limestone-grinder, lime-distributors, &c.). pp. 411–12 : How to burn limestone. p. 495 : How to apply lime.

Vol. 13 (July–December, 1916).—pp. 3–4 : Lime-supply for New Zealand soils (J. Brown). pp. 36–41 : Notes on soils analysed (B. C. Aston) (several soils from limestone areas are discussed—Kaipara and Ward districts). pp. 87–96 : Lime and liming in Southland, &c. (W. D. Hunt). p. 275 : Lime and superphosphate for combating bush sickness—lime alone seems to do harm.

Vol. 14 (January–June, 1917).—p. 75 : Limestone reports considered by the Board of Agriculture. pp. 125–32 : Lime for estuarial lands, &c. (D. M. Ross). pp. 221–22 : Report on liming-tests in Canterbury (A. McTaggart). pp. 222–23 : Lime, &c., on pakihi land, Westport. p. 241 : Shells at Kerikeri, Bay of Islands; use of "Jeffrey Pulver" for grinding advised. p. 246 : Carriage of lime by sea and rail. pp. 271, 272 : Calcareous claystones, greensands, &c. p. 416 : Reports and analyses of limestone submitted to Board of Agriculture; lime from Hauturu, near Kawhia.

Vol. 15 (July–December, 1917).—p. 14 : Liming peaty soils (Waikato). p. 29 : Lime treatment for potato-blight. p. 29 : Pulverizing shells at Awanui, &c. p. 30 *et seq.* : Use of lime-sulphur spray. p. 37 : Burnt lime used near Greymouth. p. 190 : Test of patent "Lightning" crusher at Otira (Aston). pp. 196, 201, 303 : Beneficial effect of limestone, &c., on North Island pumice soils, &c. (Aston). p. 340 : Lime compounds in brown-coal ashes. p. 343 : Report (bulletin) on limestone-deposits mentioned.

Vol. 16 (January–June, 1918).—pp. 162–64 : Two notes on limestone (B. C. Aston). pp. 183, 184, 195 : Lime for lucerne crop. pp. 223 *et seq.* : Lime-sulphur spray, &c. p. 244 : Lime for fowls.

Additions to Literature.

The following additions to the literature on limestone and lime are inserted while this bulletin is passing through the press, but it has not been found possible to make full use of the information given in the publications mentioned. This statement applies particularly to the analyses of limestone given by Mr. B. C. Aston in the *Journal of Agriculture* for August, 1918.

1918. Wybergh, W., and Du Toit, A. L.: "The Limestone Resources of the Union," vol. 1. Union of South Africa, Geol. Surv. Memoir No. 11.

1919. Carne, J. E., and Jones, L. J.: "The Limestone Deposits of New South Wales." No. 25 of Mineral Resources Series, N.S.W. Mines Department. (Not seen.)

1919. Wild, L. J.: "Soils and Manures." Published by Whitcombe and Tombs, Wellington and Christchurch.

1919. Wild, L. J., and Speight, R.: "The Limestones of Canterbury considered as a possible Source of Phosphate." N.Z. Jour. of Science and Technology, vol. 2, No. 3, May, pp. 180–92. On p. 191 references to several papers not seen by the present writers are given.

Additional references from the *New Zealand Journal of Agriculture* are as follow:—

Vol. 17 (July–December, 1918).—pp. 1–5: Liming at Motuihi, &c. p. 47: Preparation of self-boiled lime-sulphur mixture. pp. 60–61: Making concrete posts. pp. 98–102: Limestones of New Zealand: Further analyses (B. C. Aston). pp. 196–200: Some Poverty Bay soils (Aston). pp. 257–62: Liming pumice soils (Aston).

Vol. 18 (January–June, 1919).—pp. 15–26: Improvement of poor pasture (Aston). pp. 79–82: Economizing phosphates: The use of lime (Aston). pp. 140–47: Increasing agricultural production by liming, &c. (A. McTaggart). p. 242: Liming a clay soil.

CHAPTER II.

LIMESTONE IN THE NORTH ISLAND.

PAGE
Method of Presentation 35
County Boundaries ; Maps used, &c. .. 36
1. Mangonui County 36
2. Whangaroa County 41
3. Hokianga County 43
4. Bay of Islands County 44
5. Whangarei County 48
6. Hobson County 56
7. Otamatea County 58
8. Rodney County and Kawau Island .. 63
9. Waitemata County 66
10. Eden County 71
11. Manukau County 71
12. Franklin County 73
13. Barrier County, Little Barrier Island, &c. 73
14. Coromandel County 74
15. Thames County 76
16. Ohinemuri County.. 77
17. Raglan County 79
18. Waikato County 83
19. Piako County 84
20. Tauranga County 85
21. Kawhia County 85
22. Waipa County 87
23. Matamata County 88
24. Rotorua County 89
25. Whakatane County 89
26. Opotiki County 90
27. Waiapu County 91
28. Waikohu County 93
29. Cook County 96
30. Awakino County 99
31. Waitomo County 102
32. West Taupo County 107
33. East Taupo County 108
34. Wairoa County 109
35. Hawke's Bay County 111
PAGE
36. Clifton County 115
37. Ohura County 117
38. Kaitieke County 118
39. Taranaki County 119
40. Stratford County 121
41. Whangamomona County 125
42. Waimarino County 126
43. Egmont County 127
44. Eltham County 128
45. Waimate West County 129
46. Hawera County 129
47. Patea County 130
48. Waitotara County.. 131
49. Wanganui County.. 134
50. Rangitikei County.. 135
51. Kiwitea County 137
52. Pohangina County 137
53. Waipawa County 138
54. Waipukurau County 138
55. Patangata County.. 140
56. Dannevirke County 142
57. Oroua County 143
58. Woodville County 144
59. Weber County 146
60. Manawatu County.. 146
61. Kairanga County 147
62. Pahiatua County 148
63. Akitio County 150
64. Horowhenua County 152
65. Eketahuna County 152
66. Mauriceville County 154
67. Castlepoint County 156
68. Masterton County 157
69. Wairarapa South County 158
70. Featherston County 160
71. Hutt County 162
72. Makara County 162

METHOD OF PRESENTATION.

ALTHOUGH counties, with their generally artificial boundaries, are arbitrary divisions from a geological point of view, yet they are probably the most convenient areal units for everyday purposes. In this bulletin the limestone deposits of the Dominion will therefore be described for each county, taken roughly in order from north to south and from west to east. The general plan is to give a brief summary of the general geology of each county, followed by a fairly detailed description of its limestone resources. As a rule, all available analyses are quoted with full references to locality, sender, and the analytical report from which they have been derived. They are grouped in what seems the most convenient manner, and the original method of statement is adhered to as far as possible. Summaries of the limestone resources (if any) and of the means of transport are given for each county, and will probably be found of more general interest than the somewhat technical matter that usually precedes. Owing to their insertion being an afterthought some of the earlier summaries are briefer than is perhaps desirable. Each section concludes with abbreviated references to the geological literature dealing with the county under description.

County Boundaries, Maps used, etc.

In some cases difficulty has been experienced in deciding the county to which a poorly-known locality belongs, and occasional errors may have been made. Since the first institution of counties in 1877 there have been many changes in boundaries, more especially in the direction of forming new counties, a movement that has not yet ceased. The chief maps used in deciding county boundaries were the coloured county maps of the North and South Islands, on the scale of ten miles to the inch (drawn by W. Deverell), issued during 1918 by the Lands and Survey Department. The county maps on the scale of one inch to the mile were also used, but the Geological Survey does not possess a full set of these maps, nor has it sufficient office accommodation for the spreading-out and handling of a large number of maps at one time. Practically all important localities are indicated on the maps accompanying this bulletin. Some unimportant place-names mentioned in the bulletin are omitted from the maps, but as a rule the text will be found to indicate their position with sufficient detail for most purposes. In a few cases it has not been possible to ascertain the exact position of some of the obscure localities mentioned in old reports.

1. Mangonui County.

The spelling of the name "Mangonui" varies, the form "Mongonui" being used in most old reports, but that adopted is believed to be the more correct. In the Counties Act it is "Mongonui," but the Postal Guide has "Mangonui." As the most northerly county of New Zealand, Mangonui is the first county to be considered under the plan outlined in the opening paragraph of this chapter.

In the far north of New Zealand, west of Spirits Bay, are some highly calcareous rocks, probably of Mesozoic age, containing what are described by McKay as "banks of fossiliferous limestone" ("Reports of Geological Explorations," No. 22, 1894, p. 90). At the east end of the bay is an impure limestone crowded with the remains of large barnacles or cirripedes, probably belonging to the genus *Hexelasma*.* The limestone bed is only 3 ft. or 4 ft. thick, and apparently does not extend over any great area. Though considered by Hector and by McKay (doubtfully) to be of Pliocene age, it is probably of Miocene age. Near the south side of the North Cape bluff, and south-east of Tom Bowline (Bowling) Bay, a limestone layer composed of small corals, Bryozoa, and Foraminifera outcrops on the shores of a little bay. McKay, who discovered this limestone, gives no particulars of the quantity or quality of the rock. From his description and map, however, it is clear that the outcrop is not extensive. The age is probably the same as that of the cirripede limestone mentioned above.

Hydraulic (impure clayey) limestone occurs on the coast north-east of Parengarenga, and the same rock is also found on the south side of the western arm of Parengarenga Harbour near Yates's homestead. In this latter locality the shales and sandstones some distance below the limestone contain numerous calcareous concretions, many of which are covered by a layer of cone-in-cone limestone.†

South and south-west of Doubtless Bay, in the Oruru Valley, and on the northern slopes of the Maungataniwha Range, is a belt of limestone which, though described by Hector as "often remarkably pure and compact," is apparently on the whole not of very good quality (see analyses quoted below). In Victoria Valley and elsewhere the rock is quarried for roadmaking purposes. Near Awanui and at the Herekino River, south of Ahipara, similar limestone is found. Although the reports available do not enable the limestone-bearing areas to be exactly defined, the rock is evidently found at many points in the southern part of Mangonui County. It is generally called by McKay the "hydraulic limestone," a name implying that it is impure, and probably of Cretaceous age.

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* See also p. 69.

† For definition of cone-in-cone limestone see glossary at end of bulletin, or a paper by A. Hamilton in Trans. N.Z. Inst., vol. 34, 1902, pp. 447–51; "On the Septarian Boulders of Moeraki, Otago," and plates xxxiv and xxxv.

In the extreme east of Mangonui County, near Whangaroa Harbour, there is an area of Mesozoic or older rocks, which possibly contains small bands of marble similar to those occurring between Tauranga and Kairauwaru bays, in Whangaroa County.

The blown (dune) and beach sands of Mangonui County are in places strongly calcareous. This was observed by McKay in 1894, and in 1910 Bell and Clarke wrote: "Some of the sands near Cape Maria van Diemen and in Spirits Bay consist *entirely of comminuted shells*."* It is evident that the dune-sands, if fixed, would form a passable soil, and the more calcareous portions may actually be worth transporting to districts where the land needs lime.

At Awanui, and probably elsewhere, there are large deposits of shells on beaches or in banks. Samples from these have analysed as high as 93 per cent. of carbonate of lime.† During 1917 shells from a bank near Awanui Heads were being collected and ground for agricultural purposes by Mr. Dunlop Smith at his works, Awanui.

The following analyses of limestone and calcareous rock from Mangonui County are available:—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Silica (SiO_2) or insoluble	22·25	44·68	39·97	18·90	25·25	33·28	35·41	3·80
Alumina (Al_2O_3)	..	..	1·12	1·00	2·05	2·27	2·06	trace
Iron oxides (FeO and Fe_2O_3)	2·21	2·63	0·28					1·60
Water (H_2O)	1·12	2·01	0·14	..	..	..	..	..
Calcium carbonate ($CaCO_3$)	71·45	48·84	55·50	78·21	70·88	62·27	61·49	94·37
Magnesium carbonate ($MgCO_3$)	2·97	1·84	2·99	0·30	1·82	2·18	1·04	0·23
	100·00	100·00	100·00	98·41	100·00	100·00	100·00	100·00
Quicklime (CaO) in calcined stone, per cent. (Aston)	..	..	..	68	58	48	47	90

References.—(1) So-called lithographic limestone, said to be from Parengarenga, but probably from Oruru Valley. Col. Mus. and Lab. 27th Ann. Rep., 1893, p. 27. Lab. No. 6067/1.

(2) Highly siliceous limestone, said to be from Parengarenga, but perhaps from some other locality. Col. Mus. and Lab. 27th Ann. Rep., 1893, p. 27. Lab. No. 6067/2.

(3) Near Awanui. Col. Mus. and Lab. 20th Ann. Rep., 1885, p. 41. Lab. No. 3948. The analyst (W. Skey) states that the rock is "not rich enough to burn into lime, but would prove to be an excellent building-stone if tried."

(4) Kaitaia. B. C. Aston‡ in the *Journal of Agriculture*, vol. 11, No. 3, Sept., 1915, p. 236. Analyst's number, G 156; date, 1906. Two other samples (G 154 and G 155) with 63·61 and 59·89 per cent. of calcium carbonate are also mentioned. (See also 5th Ann. Rep. Dept. Agri., Chemistry Division, 1906, p. 112.)

(5) (6) (7) Victoria Valley. Dom. Lab. 47th Ann. Rep., 1914, p. 22. "Undetermined" is included with magnesium carbonate. Lab. Nos. D 421/1, 2, 3.

(8) Hard compact grey limestone, veined with calcite, forwarded by Thomas Ball, Mangonui, to New Zealand Exhibition, 1865. Hector, J., and Skey, W.: "Reports and Awards of the Jurors, N.Z. Exhibition, 1865," Dunedin, 1866, App. A, pp. 392, 448. Analyst's number, 9. (See also appendix to Chapter III of this bulletin.)

The limestones represented by these analyses probably all belong to what McKay called the hydraulic limestone, and if so are probably of Cretaceous age. The analyses, so far as can be judged, show that most of the Mangonui limestones are siliceous or arenaceous (sandy) rather than argillaceous (clayey), and if so they differ considerably from the typical hydraulic limestone of the Whangarei and other districts farther south. Other information to hand confirms this interpretation. At Whangarei and Warkworth the so-called hydraulic limestone is argillaceous and is used for making cement, but a limestone with 20 per cent. or so of sand instead of clay would not be suitable for cement-manufacture. It might, however, be valuable for agricultural purposes, and could probably be successfully used for the production of quicklime, whereas the argillaceous limestone would most likely form a clinker in the kiln, which would require to be finely ground before application to the soil.

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* J. M. Bell and E. de C. Clarke: "A Geological Reconnaissance of Northernmost New Zealand." Trans. N.Z. Inst., vol. 42, 1910, p. 621. The italics are those of the present writers.

† B. C. Aston in the *Journal of Agriculture*, vol. 15, No. 1, July, 1917, p. 29.

‡ Many of Mr. Aston's analyses are quoted from the *Journal of Agriculture*, vol. 11, 1915, and not from the original sources (his annual reports), most of which were not available until this bulletin was nearly completed.

In the eight analyses quoted it happens that in each case the matter insoluble in acid was determined, and that there was no exact determination of silica. Hence the "insoluble" reported contains other matter besides silica, and doubtless included a little iron oxide and alumina, or in some cases possibly a good deal. When a number of analyses is tabulated it is generally not convenient to give all the details, and in order to ascertain the method of analysis reference to the original is usually necessary. In many cases valuable remarks are appended by the analyst to the analysis. For this reason full references to all analyses quoted in this bulletin are given.

Unfortunately none of the limestones represented by the analyses, except No. 8 (a picked sample of doubtful locality), is of really good quality. Nos. 1, 4, and 5 are the best of the others, and, if no better stone is obtainable, may be considered suitable for the production of pulverized limestone. If calcined, No. 4 would produce a quicklime theoretically containing about 68·7 per cent. of calcium oxide, a little magnesium oxide, and about 31·2 per cent. of sand, &c. Nos. 1 and 5 are too poor to be worth burning, and very probably neither could be successfully calcined in any case.

There are at least two important defects in connection with the analyses quoted: one is that the exact locality of the sample analysed is in no case given, and the other is that in no case can even the roughest estimate of the quantity of limestone of the quality represented by the analyses be made. A third defect is that in all probability the samples, or some of them, were not taken in such a way as to be representative of a mass of limestone (see remarks on sampling, Chapter I, pp. 26–30). Similar lack of important data attends most of the analyses quoted later on. It is, of course, no part of the duty of the chemist who analyses a sample sent to him from a distance to ascertain its full history, but the sender should always supply such particulars as he can for record by the analyst.

In the early part of 1917 Mr. M. Ongley, Assistant Geologist, visited Victoria Valley, Kaitaia, and Awanui in order to examine the limestone deposits of that part of Mangonui County. Samples collected by him were analysed in the Dominion Laboratory with the following results:—

Nature of Material.	Locality.	Calcium Carbonate per Cent.
(1) Argillaceous limestone	Charles White's, Victoria Valley, eight miles east of Kaitaia	57·5
(2) ,, ..	Merton's Quarry, three miles east of Kaitaia ..	66·0
(3) ,, ..	Elmsly's, north-east of Kaitaia	71·5
(4) ,, ..	Old quarry No. 1, Kaitaia–Awanui Road ..	66·0
(5) ,, ..	Old quarry No. 2, Kaitaia–Awanui Road ..	63·0
(6) ,, ..	Old quarry No. 3, Kaitaia–Awanui Road ..	68·0
(7) ,, ..	Mangonui County Quarry, Kaitaia–Awanui Road	47·5
(8) ,, ..	Simson's Quarry, Kaitaia–Awanui Road ..	54·5
(9) Calcareous mudstone ..	Mrs. Mary Longon's Quarry, Kaitaia-Awanui Road	32·0
(10) Shells	Shell-bank, Awanui Harbour (Rangaunu Bay) ..	88·0
(11) ,, ...	Shell-beach, Blakeney Point, north-east of Rangaunu Bay	90·5

The following particulars have been compiled from Mr. Ongley's notes :—

(1) The outcrops of limestone on Mr. Charles White's land (Sections 61, 62, and 64, Block VII, Takahue Survey District) extend over a large area, 150 ft. to 500 ft. above sea-level, but the quality of the stone is poor. No bedding-planes, and therefore no strike, can be distinguished. The rock is dense, fine-grained, and of greyish colour. It appears to have been shattered, and is traversed by veins of calcite up to 2 in. thick. Mr. White has burned some of the limestone for making cement for chimneys, &c. His experience, however, has led him to think that the rock is more suited for use as a building-stone than for making lime. The sample analysed was obtained from Section 62.

(2) Merton's Quarry is situated about three miles east of Kaitaia, on Section 2346, Block VI, Takahue Survey District, and is on a branch road, 6 chains from the Kaitaia–Mangonui Road. The barometric height of the quarry above sea-level is 105 ft. The rock here is being worked for roadmaking, and is a dense argillaceous limestone, coarser-grained and darker in colour than that at White's. It is exposed in the road-cuttings for a total distance of 3 chains. The largest face is 20 ft. long and 15 ft. high. The limestone strikes 85° east of north on a true bearing, and dips steeply at 60° to the east of south. The stone is not badly crushed, but the presence of calcite veins and of slickensides (polished or scratched surfaces) shows that it has been subjected to movement. Similar stone to that of Merton's Quarry is said to occur on the hill half a mile to the east, and to have been worked in order to obtain roadmaking material.

(3) At Elmsly's, north-east of Kaitaia (Sections N. 4 and S. 4, Block VI, Takahue Survey District), the hills consist chiefly of calcareous mudstone, striking south-east 145°, and dipping at 18° to the south-west. Argillaceous greyish-white limestone similar to White's, and weathering to a brown colour, also occurs. The sample analysed comes from Section N. 4.

(4) The first quarry north of Kaitaia is on Section 242, Block V, Takahue Survey District, at the head of the south branch of a small gully, but has been badly worked, and is now disused. It is half a mile east of the Kaitaia–Awanui Road, 70 ft. above the Kaitaia Plain, and 155 ft. above sea-level. The rock here, like that of all the other quarries in the district, has been quarried for roadmaking purposes. It is a fine-grained grey argillaceous limestone, striking south-south-eastward 155°, and dipping at 25° to the south-west. It is easy to quarry, but not of good quality. A 15 ft. face, covered by 8 ft. of soil, is exposed.

(5) In the middle branch of the same gully as that in which the last-described quarry occurs is another disused quarry, where stone similar to that in the first quarry has been worked. Twelve feet of limestone is visible at the face, which, however, is now almost hidden by a slip. In the north branch of the gully is another disused working. The face shows 35 ft. of limestone, similar to that in the quarries to the south. It strikes south-eastward 145°, and dips at 25° to the south-west. Sample No. 5 (63 per cent. $CaCO_3$) was taken from this quarry.

(6) A quarter of a mile north of the last-mentioned quarry is another disused working, showing a 15 ft. face of grey argillaceous limestone with numerous small calcite veins.

(7) The Mangonui County Quarry is about two miles north of Kaitaia and a mile east of the Kaitaia–Awanui Road. It is situated on Section 24, Block II, Takahue Survey District, at a barometric height of 120 ft. above sea-level. The face is 40 yards long and 50 ft. high, capped by 4 ft. of soil. The rock quarried is argillaceous limestone, similar to that in the old quarries to the south. It is slickensided, and contains calcite veins. The strike is to the south-eastward 145°, and the dip 8° to the south-east. More limestone outcrops on higher ground to the south.

(8) Simson's Quarry is on Section 11 S.E., Block I, Takahue Survey District, about a mile north of the County Quarry, and three-quarters of a mile east of the Kaitaia–Awanui Road. Its height above sea-level is approximately 150 ft. The limestone here appears more argillaceous, and is darker than that of the County Quarry. Its strike is north-easterly 45°, and its dip 15° to the north-west. The bottom 8 ft. of the face appears the best; above there are poorer bands. The quarry is not now being worked.

(9) The Kareponia Quarry is about a mile and a half north of Simson's. It was not visited, the quarry, it is said, being worked out. Judged by material on the road, the rock of this quarry is a calcareous grit.

(10) Mrs. Mary Longon's Quarry is on the Kauri-gum Reserve (Pairatahi) in the north-west part of Block XI, Rangaunu Survey District, two or three miles north-east of Awanui Township. The rock here is a calcareous arenaceous dark-grey mudstone, which forms a number of hills in the neighbourhood. Barges easily reach the quarry by way of the Pairatahi Stream.

(11) In Awanui Harbour (Rangaunu Bay) there are several shell-banks, material from which is being taken by Mr. Dunlop Smith, and pulverized at Awanui in a "Devil" disintegrator. Much the greater part of the material forming these banks is shell, and it is an easy matter to separate the sand and obtain pure shell.

(12) At Blakeney Point, north-east of Rangaunu Bay, there is a beach of almost pure shell, a quarter of a mile long, 15 to 30 yards wide, and in places over 5 ft. deep. The shells are much broken, and in places are so comminuted as to form a fine pure white sand. The shell deposit can easily be loaded into scows or barges.

Summary of Limestone Resources and of Means of Transport.

The limestones of Mangonui County so far as known are, on the whole, low grade, and not suitable for calcination. They must therefore be used by the agriculturist in the powdered state. The shell deposits of the bays and harbours appear to be of considerable value, and may be used, if desired, for making quicklime. The shells may also be spread direct on the land, with or without preliminary crushing. In places shell sands, both on the beaches and in sand-dunes, occur. The eastern coast of the county, with its numerous harbours, has good external communications, but roads are generally poor or in places non-existent, and therefore means of internal communication and transport are poor.

Literature.

The principal references to the geology of Mangonui County are contained in the following publications:—

Reports of Geological Explorations, No. 7, 1872, pp. 155–58; No. 21, 1892, pp. lxxxi–lxxxii, lxxxiii–lxxxiv, 73–76; No. 22, 1894, pp. xvi–xxi, 70–90. Only in the last of these are there important references to limestone.

Mines Report, 1899, C.–9, pp. 14, 15. Lithographic limestone of Oruru Valley described.

"Transactions of the New Zealand Institute," vol. 42, 1910, pp. 613–24.

New Zealand Geological Survey Bulletin No. 8, 1910. A small area in the extreme east of Mangonui County is described and geologically mapped in detail. No limestone is known to occur in this area.

Note.—On future pages "Reports of Geological Explorations" will be abbreviated to "Rep. of Geol. Explor.," "N.Z. Geological Survey Bulletin" to "N.Z. Geol. Surv. Bull.," and "Transactions of the N.Z. Institute" to "Trans. N.Z. Inst."

2. WHANGAROA COUNTY.

The greater part of Whangaroa County has been geologically surveyed in detail, and the results are embodied in N.Z. Geol. Surv. Bull. No. 8, published in 1908: "The Geology of the Whangaroa Subdivision, Hokianga Division."

Throughout a considerable extent of country south, south-east, and east of Whangaroa Harbour there are numerous outcrops of impure shaly limestone, probably of Cretaceous age. The rock, however, perhaps owing to its soft character, is not prominently developed. North-east of Kaeo, on the Kaeo–Mangonui Road at the turn-off to Whangaroa, and again half a mile to the west, soft marly limestone may be seen. In the lower part of Pupuke River and in many other places shales, claystones, and sandstones with calcareous concretions occur. The concretions are described by E. de C. Clarke as consisting of quartz sand cemented by about an equal amount of carbonate of lime (N.Z. Geol. Surv. Bull. No. 8, p. 51). McKay mentions also the occurrence of masses of cone-in-cone limestone (Rep. of Geol. Explor. No. 9, pp. 56, 57).

In Towai Creek, about half a mile above Towai Settlement, a siliceous limestone of Cretaceous or later age having the following composition occurs:—

Silica (SiO_2)	27·10
Alumina (Al_2O_3)	4·01
Ferric (iron) oxide (Fe_2O_3)	2·32
Lime (CaO)	35·61
Magnesia (MgO)	0·15
Carbon dioxide (CO_2)	26·70
Water and organic matter	2·32
Undetermined (alkalies and other substances)	1·79
	100·00
Calcium carbonate ($CaCO_3$), by calculation (per cent.)	60·31

References.—N.Z. Geol. Surv. Bull. No. 8, 1909, p. 55; Dom. Lab. 42nd Ann. Rep., 1909, p. 21 (locality wrongly recorded as Hokianga). Lab. No. 1842/3.

The 35·61 per cent. of calcium oxide or lime of the above table would require 27·98 per cent. of carbon dioxide to convert it wholly into calcium carbonate, whereas the analysis shows only 26·70 per cent. of carbon dioxide as present. If we suppose, as is usual, that the magnesia is combined as carbonate, then the 0·15 per cent. of magnesia or magnesium oxide present will be combined with 0·165 per cent. of carbon dioxide to form 0·315 per cent. of magnesium carbonate. This leaves 26·535 per cent. of carbon dioxide free to combine with calcium oxide to form calcium or lime carbonate. On this basis the approximate amount of calcium carbonate present will be 60·31 per cent., and not 63·59 per cent., as would be calculated on the supposition that all the lime was in the form of carbonate. The mineral composition of the Towai rock as inferred from the analysis will be, approximately—

Free silica and silicate minerals of various kinds	37·06
Carbonate of lime (calcite)	60·31
Carbonate of magnesia	0·31
Water (organic matter may be neglected)	2·32
	100·00

Part of the water, probably the greater part, is combined with silicate minerals.

South of Towai Creek the siliceous limestone, of which an analysis is given above, seems to pass into a poorly calcareous sandstone. A sample, probably representing a calcareous concretion, was collected by the Geological Survey in Tangitu Creek (near or possibly within Bay of Islands County boundary) and analysed by the Dominion Laboratory in 1908 (Lab. No. 1847/2). The analysis is as follows:—

Ferric oxide (Fe_2O_3)	3·17 per cent.
Lime (CaO)	51·11 ,,
Carbonic anhydride (CO_2)	40·20 ,,

The sample therefore contained about 91·3 per cent. of carbonate of lime.

Reference.—Dom. Lab. 42nd Ann. Rep., 1909, p. 48. (Analysis not given. Recorded as "iron-ore.")

On the coast two or three miles east of the entrance to Whangaroa Harbour, between Tauranga and Kairauwaru bays, several layers of crystalline limestone, or rather marble, of a white or greyish-white colour outcrop in various places. This rock occurs in Clarke's Waipapa Series, which is believed to be of Late Palæozoic or Early Mesozoic age. The beds, which are apparently never more than 6 ft. thick, are much shattered, and are mixed with the associated volcanic and sedimentary rocks. This marble is apparently of great purity, as is shown by the following analysis of a sample from the neighbourhood of Shag or Kairauwaru Bay:—

Silica (SiO_2)	0·95
Alumina (Al_2O_3)	0·55
Ferric (iron) oxide (Fe_2O_3)	0·70
Lime (CaO)	54·00
Magnesia (MgO)	0·50
Carbon dioxide (CO_2)	42·43
Water and organic matter	0·72
Alkalies and undetermined	0·15
	100·00
Calcium carbonate ($CaCO_3$), by calculation (per cent.)	95·18

References.—N.Z. Geol. Surv. Bull. No. 8, 1909, p. 45, and Dom. Lab. 42nd Ann. Rep., 1909, p. 20 (locality wrongly recorded as Camp Bay, Hokianga). Lab. No. 1835/1. The calcined stone will contain approximately 95 per cent. of quicklime (CaO).

After allowance for the magnesia present has been made the carbon dioxide of the above analysis is reduced to 41·88 per cent., and may be considered as combined with 53·30 per cent. of the lime to form 95·18 per cent. of carbonate of lime. This leaves a surplus of 0·70 per cent. of lime, only part of which can in this case be considered as combined to form silicates. There is therefore a remainder unaccounted for, indicating small errors in the analysis (these are unavoidable, as explained on page 12), and possibly that only part of the magnesia is combined as carbonate.

Summary of Limestone Resources and of Means of Transport.

The available information shows that Whangaroa County is not rich in limestone deposits. The scanty marble beds are of good quality, but, so far as has yet been ascertained, are not thick or well situated for quarrying. Future discoveries may improve the situation, especially if marble deposits fit for building and ornamental purposes are found. The waste from the quarries will then be available for agricultural purposes at a low price. The fine harbour of Whangaroa affords good means of communication with Auckland and other parts of New Zealand, but there are no railways, and many of the roads are poor, so that internal communications at the present time are imperfect.

Literature.

The principal references to the geology of Whangaroa County are contained in the following publications :—

Rep. of Geol. Explor., No. 7, 1872, pp. 153–54 ; No. 9, 1877, pp. 55–58 ; No. 21, 1892, pp. lxxx–lxxxiii, 65–72, 155 ; and No. 22, pp. 70–90.

Mines Rep., 1898, C.–9, pp. 4–5. Deals with copper only.

N.Z. Geol. Surv. Bull. No. 8, 1909. This describes a great part of the county and small portions of adjoining counties. Other publications are listed in N.Z. Geol. Surv. Bull. No. 8, pp. 12–14.

3. HOKIANGA COUNTY.

Hokianga County has been but little explored by the geologist, although a small portion, forming part of the Whangaroa Subdivision, was surveyed in detail by E. de C. Clarke ten or eleven years ago (see Geol. Surv. Bull. No. 8), and several visits to the county were made by McKay and Hector. The massive but somewhat impure limestones which outcrop in Bay of Islands County west and south-west of Lake Omapere extend into Hokianga County, and are seen at the head of Te Karu Creek. According to McKay (see Rep. of Geol. Explor. during 1883–84, No. 16, 1884, p. 131), the country in the neighbourhood of the upper part of Hokianga Harbour is largely formed of hydraulic (argillaceous) limestone, of probable Cretaceous age. Similar rock occurs to the north-west, in the valleys of the streams draining into Whangape Harbour, and in the Herekino River valley.

The point to the north of the entrance to the Waihou River (Hokianga Harbour) opposite Horoeke is formed of hydraulic limestone, and some distance up the river flaggy limestone outcrops at a supposed lower horizon. Some distance up the Mangamuku River is a limestone gorge. At The Narrows, near Kohokohu, is a bed of shelly limestone, composed mainly of a small oyster. In a higher horizon are shaly clays, containing concretions and thin bands of limestone. The fossil contents of these rocks indicate a Cretaceous age. Near Kohukohu (probably) there is a deposit of calcareous sinter (travertine), analyses of which are quoted below, but no information regarding the size of the deposit has been obtained.

At the base of Miocene conglomerates outcropping from the mouth of the Waimamaku River to Hokianga South Head and for some distance inland is a bed, 12 ft. to 15 ft. thick, of calcareous sand, or limestone. This possibly is represented by analyses (3) and (4) quoted below.

The southern and south-eastern parts of Hokianga County are geologically almost unknown.

The following analyses of limestones from Hokianga County are available :—

	(1)	(2)	(3)	(4)	(5)
Siliceous matter insoluble in acid ..	6·25	2·97	8·93	16·51	..
Alumina and iron oxides (Al_2O_3, Fe_2O_3)	1·01	0·91	0·68	1·12	..
Water (H_2O)	0·62	0·60	..	..	..
Calcium carbonate ($CaCO_3$)	89·98	93·14	89·75	82·27	73·58
Magnesium carbonate ($MgCO_3$) ..	2·14	2·38	0·64	0·10	..
	100·00	100·00	100·00	100·00	..
Quicklime in calcined stone (per cent.) (Aston)	83	90	83	74	..

References.—(1) (2) Calcareous sinter, Kohukohu, forwarded by Mr. Bacon through the Secretary for Agriculture. Col. Mus. and Lab. 33rd Ann. Rep., 1900, p. 9. Lab. Nos. 8345/1, 2. The analyst (W. Skey) remarks that the material " would burn into fairly good lime, and also crush very easily to a fine powder " which could be applied direct to the land.

(3) (4) From Waimamaku, forwarded by Mr. A. V. Pettman. Dom. Lab. 48th Ann. Rep., 1915, p. 21. Lab. Nos. E 897/1, 2. The " magnesium carbonate " of these analyses includes " undetermined."

(5) From Kohukohu, forwarded by G. H. Neill in 1916. Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. No. G 53. Phosphoric anhydride (P_2O_5) present in very small amount (0·06 per cent.).

Summary of Limestone Resources and of Means of Transport.

Too little is known about the limestone deposits of Hokianga County to enable an opinion as to their availability, quantity, and quality to be expressed. Hokianga Harbour can be entered by fairly large vessels, and has deep water inside the bar.* It therefore gives the main part of the county good sea communications, and its numerous arms afford a certain amount of internal communication. The county is poorly supplied with roads, and at the present time has practically no railways, though the Dargaville–Kaihu Railway has been extended three miles past Kaihu to Tarawhati, which is in the south-west corner of the county. The Kawakawa–Kaikohe Railway comes close to the eastern boundary, and will ultimately be extended to Horoeke, on Hokianga Harbour, thus giving railway communication with Bay of Islands, Whangarei, &c.

Literature.

The chief references to the geology of Hokianga County are the following :—

Rep. of Geol. Explor., No. 16, 1884, parts of pp. 110–34 ; No. 19, 1888, pp. 48–53, 55–57 ; No. 21, 1892, p. 155 ; No. 22, 1894, pp. 70-90.

N.Z. Geol. Surv. Bull. No. 8, 1909. Describes only a small area in the north-east of Hokianga County.

4. Bay of Islands County.

Many years ago at the head of Waikari (or Waikare) Inlet Sir James Hector discovered limestones associated with slates, sandstones, and other rocks of Mesozoic or older age (Rep. of Geol. Explor. No. 22, 1894, p. 88). In the gorge of the Waipapa River, in the north-west part of Omapere Survey District, an impure crystalline limestone or marble occurs. This occurs in Clarke's Waipapa Series, and may probably be roughly correlated with the so-called limestone just mentioned as discovered by Hector.

Skey's analysis of a sample of the crystalline limestone from Waikari Inlet, collected by Sir James Hector, is as follows :—

Carbonate of lime ($CaCO_3$)	94·59
Carbonate of magnesia ($MgCO_3$)	2·96
Siliceous matter	0·81
Water (H_2O)	0·23
Iron oxides (FeO and Fe_2O_3)	Trace
Alumina (Al_2O_3)	1·41
	100·00

Reference.—Col. Mus. and Lab. 27th Ann. Rep., 1893, p. 36. Lab. No. 6046.

According to Clarke massive limestones of probable Cretaceous age occur to the east of the Waipapa Gorge mentioned above, in the middle part of Pirau or Waiohanga Stream watershed, whence they strike south-east into the valleys of the Waikaraka Stream and its tributaries the Arotoro and Poro-te-Koihamo. In this neighbourhood they are fairly well developed, and of better quality than is usual elsewhere in the district. Limestone is again seen some miles to the east in the Waitangi and its tributaries, the Awahei and Waikuku creeks. South-west of Lake Omapere isolated outcrops of arenaceous limestone appear in the Waiharakeke and Waihoanga (Waihanga) creeks, not far above their junctions with the Utakura (the outlet stream from Lake Omapere).

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* The depth of water on the bar at low water, spring tides, is 16 ft. : " The New Zealand Pilot," 1856 (published by British Admiralty), p. 151.

McKay states that hydraulic limestone occurs in the hilly country west of Lake Omapere and the Okaihau tableland. The following statement probably refers to the upper valley of the Whakanekeneke Stream: "Just to the north of Mr. Nicholson's homestead the hydraulic limestone crops out from underneath the volcanic rocks, and has there been burned, and used as ordinary mortar-lime."[*] The latter part of McKay's remarks fits in with Skey's reference to burning limestone from Okaihau, quoted below.

The following analyses show that the limestones of Omapere Survey District are for the most part of moderate quality :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Silica (SiO_2) or insoluble matter ..	8·40	35·21	35·38	37·10	14·25	18·53	22·10	49·67
Alumina (Al_2O_3)	3·01	8·20	7·79	1·54	3·66	2·66	2·29	8·31
Ferric oxide (Fe_2O_3)				3·01	3·88	1·52	2·96	2·56
Lime (CaO)	47·55[†]	30·19[†]	30·23[†]	32·80	43·25	39·90	37·52	17·58
Magnesia (MgO)	1·25[†]	0·91[†]	0·88[†]	1·10	0·15	0·88	0·85	1·31
Carbon dioxide (CO_2)	38·73[†]	24·73[†]	24·71[†]	22·84	33·65	31·43	29·47	13·82
Water and organic matter ..	1·06	0·76	1·01	0·56	0·45	2·24	2·21	5·66
Alkalies and undetermined ..	..	..	..	1·05	0·71	2·84	2·60	1·09
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Calcium carbonate ($CaCO_3$), by calculation (per cent.)	84·91[‡]	53·91[‡]	53·98[‡]	49·16	76·10	69·23	64·85	28·13
Magnesium carbonate ($MgCO_3$), by calculation (per cent.)	2·62[‡]	1·92[‡]	1·84[‡]	2·31	0·315	1·85	1·785	2·75
Quicklime (CaO) in calcined stone (per cent.)	79	..	..	..	64·4	57·6	..	..

References.—(1) (2) (3) Calcareous rocks from Okaihau, forwarded by Mr. R. Blundell. Col. Mus. and Lab. 17th Ann. Rep., 1882, p. 32. Lab. Nos. 3178/1, 2, 3. The analyst remarks that "No. 1 is a fairly good limestone, and would do for burning into lime, but owing to the rather large quantity of silica present care would have to be taken at the kiln lest it get overburned. For a building-stone it is somewhat too shaly. No. 2 and No. 3 are calcareous sandstones, and well adapted for building-stones."

(4) Impure arenaceous limestone from Pirau Stream, about 30 chains north-west of Trig. Station M. N.Z. Geol. Surv. Bull. No. 8, 1909, p. 53; Dom. Lab. 42nd Ann. Rep., 1909, p. 20. Lab. No. 1835/3.

(5) White limestone from the lower part of Waikaraka Stream, about a mile above its junction with the Whakanekeneke Stream. Same references as No. 4, but p. 21 of Dom. Lab. Rep. Lab. No. 1842/4.

(6) Arenaceous limestone from the Pukehemoa or Waikuku Stream, about half a mile north of the road from Waimate North to Okaihau Road. Same references as No. 5. Lab. No. 2026/3. Wrongly recorded in the Geological Survey bulletin as from Waikaraka Stream.

(7) Arenaceous limestone from Awahei Creek, about a quarter of a mile above its junction with the Waitangi Stream. Same references as No. 5. Lab. No. 2026/2.

(8) Arenaceous limestone, or perhaps more correctly a calcareous sandstone, from the Waitangi Stream, about a quarter of a mile below the point where it is joined by the Awahei Creek. Same references as No. 5. Lab. No. 2026/4.

South and south-south-east of Kawakawa there is a moderate development of a hard light-grey or reddish subcrystalline limestone. The strike is roughly north and south, the dip at moderate angles to the west. Drilling in the neighbourhood of the now abandoned Kawakawa Coal-mine shows that the limestone has a thickness of from 208 ft. to 249 ft. In this locality the limestone is not seen, being covered by surface deposits. Farther south, in the valley of Waiomio Stream and elsewhere, are fantastically weathered outcrops, with numerous caves. These are described in some detail by McKay.*

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[*] Rep. of Geol. Explor. during 1887–88, No. 19, 1888, p. 49.

[†] Recalculated from data of original analyses, which give carbonates of lime and of magnesia.

[‡] These percentages are given in the original analyses.

The quality of the limestone is variable. At Waiomio Caves calcareous conglomerate of brown colour forms the lowest beds, but to the north-west this passes into reddish gritty limestone full of broken shells and other organic remains. The middle and upper beds as exposed in outcrops are grey or white in colour, and appear to be of good quality. According to McKay they resemble the limestone near Kamo, about twenty-three miles as the crow flies to the south-south-eastward.

In the neighbourhood of Ngapipito and Rakautao the cuttings on the Kawakawa–Kaikohu Railway show bluish claystone, which is probably calcareous. Chalky-looking pebbles occur in some of the stream-beds.

From Towai northward to near Pokapu, at thirty to forty-three miles on the Onerahi–Whangarei–Opua Railway, the cuttings show many outcrops of bluish calcareous claystone. Near Motatau, and again near Pokapu, what appears to be impure limestone is exposed.

Two samples from Motatau, sent to the Dominion Laboratory in 1916 by Mr. Tau Henare, M.P., yielded on analysis 64·50 and 95·50 per cent. of calcium carbonate. (Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. Nos. 1929/1, 2.) The following note is appended to the analyses: "When dried and crushed No. 2 would be worth 17s. 6d. per ton as agricultural lime. No. 1 is not sufficiently rich in lime to make a good fertilizer."

An analysis of cement-stone from Towai is as follows:—

Silica	24·51
Alumina	3·41
Iron-oxide	1·66
Lime	38·00
Magnesia	0·74
*Carbonic anhydride	28·80
Moisture and organic matter	2·57
Alkalies and undetermined	0·31
	100·00
Quicklime (CaO) in calcined stone (per cent.)	55·37
*Equivalent to calcium carbonate (per cent.)	65·45

Reference.—Forwarded by J. J. Craig (Limited). Dom. Lab. 45th Ann. Rep., 1912, p. 16. Lab. No. B 427. Composition of burnt stone also given.

In an unpublished report written in 1909, Mr. J. C. Neill, at that time an officer of the Geological Survey, writes that east of the railway-line near Towai, on the flanks of the Ruapekapeka Range, and notably in Smith's Creek, there may be observed good exposures of the limestones, sandstones, and shales characteristic of the Kawakawa and Hikurangi coal-measures. Near Koraha Post-office, at the north-west end of the Ramarama Valley, the Ramarama Stream cuts through the anticlinal fold on the north and east; and in the gorge and railway-cuttings a considerable thickness of limestone is exposed, but it is of so shattered a nature that no definite stratification-planes can be observed. On the south-west side of the valley near the Papakotai Hills no limestone was observed, probably owing to its having been denuded. Limestone, however, outcrops on a parallel ridge three miles farther to the south (probably in the northern part of Whangarei County near Aponga).

The exact locality of the limestone represented by the following analysis (No. 1) is unknown. It was forwarded to the Colonial Laboratory by Mr. W. Fuller, and is described by Skey as "a compact limestone from Russell." It may possibly have come from the Waiomio limestone near Kawakawa. An analysis of earthy limestone from Turntable Hill (No. 2) is also given. Turntable Hill is near Pakaraka.

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* McKay, Alex.: Rep. of Geol. Explor. during 1883–84, No. 16, 1884, pp. 126, &c.

	(1)	(2)
Carbonate of lime	82·56	74·20
Carbonate of magnesia	3·34	3·42
Alumina and iron oxides	2·69	2·68
Water	..	0·49
Siliceous matter	11·41	19·21
	100·00	100·00

References.—(1) Col. Mus. and Lab. 23rd Ann. Rep., 1889, pp. 53, 59. Lab. No. 4645 (or 4645/12).

(2) Col. Mus. and Lab. 27th Ann. Rep., 1893, p. 29. Lab. No. 6045. Sample collected by Sir James Hector.

About 1890 a vesicular limestone or travertine collected from the neighbourhood of Pakaraka by Mr. Alex. McKay was found in the Colonial Laboratory to contain 91·24 per cent. of carbonate of lime. (Col. Mus. and Lab. 25th Ann. Rep., pp. 58, 90. Lab. No. 5550.) Page 58 gives the locality as Parihaka, but on the whole it is probable that the locality was Pakaraka, as stated on page 90.

Shells are said to exist in considerable quantity on the beaches near Kerikeri (Jour. Agric., vol. 14, No. 3, March, 1917, p. 241.) Probably similar beaches exist elsewhere on the coast of Bay of Islands County.

Summary of Limestone Resources and of Means of Transport.

Portions of Bay of Islands County are well supplied with poor limestone, suitable for pulverization but not for calcination. What amount of high-grade limestone occurs is uncertain. The Bay of Islands is a splendid harbour, and with the other harbours south of Cape Brett affords good sea communications. The far-reaching arms of the Bay of Islands give a certain amount of internal communication also. To what extent these arms and those of many similar inlets on the North Auckland coast are navigable, and for what class and size of vessels, are important matters in connection with the transport of lime and other goods, but it is impossible to deal with them in a publication like the present. The railway from Whangarei enters the county at Hukerenui, and ends at Opua, close to deep water. A branch line runs from Otiria to Kaikohe. These railways enable lime from Whangarei County to be distributed to considerable portions of Bay of Islands County.

Literature.

The principal references to the geology of the Bay of Islands County will be found in the following publications:—

Rep. of Geol. Explor., No. 10, 1877, pp. 135–38 (deals with Kawakawa Coal-mine); No. 14, 1882, pp. 92–94; No. 16, 1884, pp. 95–99, 110–34; No. 17, 1886, pp. 9–10; No. 19, 1888, pp. 42–43, 48–50, &c.; No. 21, 1892, pp. xxx–xxxi and parts of pp. lxxii to lxxxii, pp. 55–59 (Puhipuhi), 59–62, 148; No. 22, 1894, parts of pp. ix to xvi, pp. xxii–xxv, 50–55 (Puhipuhi).

Trans. N.Z. Inst., vol. 23, 1891, pp. 375–79; vol. 25, 1893, pp. 375–77. These two papers by Alex. McKay deal principally with a deposit of diatomaceous earth at Pakaraka.

Mines Rep., 1898, C.–9, pp. 5–6 (Alex. McKay, on Kawakawa Coalfield). Reports by H. A. Gordon on the Puhipuhi Silverfield appear in the Mines Reports for the years 1890 to 1894, and also in the years 1896, 1897, and 1898.

Cinnabar deposits at Ohaeawai are described by Gordon in the Mines Rep. for 1895, pp. 257–59, and by A. P. Griffiths in "The Ohaeawai Quicksilver Deposits," Trans. N.Z. Inst. Min. Eng., vol. 2, 1898, pp. 48–60.

N.Z. Geol. Surv. Bull. No. 8, 1909. As already mentioned, this deals in detail with the geology of part of Bay of Islands County.

5. WHANGAREI COUNTY.

In Whangarei County two distinct kinds of limestone are well developed. Both are represented in other parts of North Auckland—one, a soft argillaceous rock, being the hydraulic limestone already mentioned, whilst the other, a hard compact crystalline rock, is generally referred to as the Whangarei limestone. The Whangarei limestone is usually of high grade, and suitable for the manufacture of quicklime, whilst the hydraulic limestone is of little use as a source of quicklime, but is extremely valuable for making cement.

The geological relation of the two limestones to each other is uncertain. In 1877 Cox, and in 1910 Park, considered that the argillaceous limestone was the older. In 1881 Cox again thought that the crystalline limestone in the Kaipara district was much younger than the hydraulic limestone, though he declared himself uncertain as to the relative position of the similar rocks in the Whangarei district. On the other hand McKay in 1884 and 1888, Park in 1887, and Marshall* in 1916 agreed that the crystalline or Whangarei limestone underlay the argillaceous or hydraulic limestone. The known field evidence, though scanty, is in favour of this latter view, but no perfectly clear section proving it has yet been observed.

All observers previous to Marshall consider the hydraulic limestone to be of Cretaceous age, but that geologist assigns it to the Tertiary, on the ground that the supposed underlying Whangarei or crystalline limestone contains Foraminifera of Eocene or Miocene age.

The hydraulic limestone itself consists largely of Globigerina remains, but otherwise, so far as known, is practically non-fossiliferous, and therefore contains no decided internal evidence of its age. Marshall's palæontological data seem to prove that the crystalline limestone is not older than the Eocene, and if the hydraulic limestone really overlies, it also must be of Tertiary age. It is, however, in several places closely associated with rocks containing Cretaceous fossils. This and other circumstances suggest a Cretaceous age, a conclusion supported by Cox, McKay, and Park. Hence it must be considered possible that the hydraulic limestone underlies the supposed younger crystalline limestone. To support this view it is necessary to assume either that the apparently superior position of the hydraulic limestone near Pahi (Kaipara), and perhaps elsewhere, is due to faulting—which is indeed very likely—or that errors in correlation have been made by some or all of the geologists who have visited the North Auckland region. The relative positions and ages of the hydraulic and crystalline limestones are not matters of moment so far as the purposes of this bulletin is concerned. For other reasons, however, the problem is one of importance, and will have to be solved before a systematic search for coal in North Auckland by boring can be reasonably undertaken. Though it is difficult, detailed geological survey will undoubtedly provide a solution. Brief casual examinations, on the other hand, are more likely to add to the present confusion than to remove it.

The crystalline or Whangarei limestone occurs at Waro near Hikurangi, at Kamo, Whauwhau Valley, and elsewhere, near the town of Whangarei, some miles west of

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* Marshall, P.: "The Younger Limestones of New Zealand." Trans. N.Z. Inst., vol. 48, 1916, pp. 87–89. References to the views of the other writers mentioned above are given.

Whangarei, at Abbey Rocks north-east of Whangarei, at Whareora, near Whangarei Heads (north side of harbour), at Horahora, south of Ruakaka River, and south of the mouth of Waipu River. The hydraulic limestone is well developed on Limestone Island (opposite Onerahi), and at Mangapai (on the south-west shore of Whangarei Harbour). Inland it seems to occupy considerable areas towards the Wairua River. The country surrounding Whangarei Harbour, and the district to the north as far as Waro, is exceptionally well supplied with limestone suitable for all purposes, and outcropping in accessible positions close to railway or to water carriage.

At Waro, fourteen miles from Whangarei, crystalline limestone forms an isolated hill just to the west of the railway-line. The fantastically weathered surface of the limestone, only partly hidden by vegetation, gives the hill a picturesque and beautiful appearance. It has therefore been often photographed, and is well known throughout New Zealand owing to the circulation of the views by means of post-cards and illustrations in the weekly papers. Plate I shows the character of the limestone fairly well.

The Waro limestone is white, reddish, or brownish in colour. It strikes north and south, and has a dip of 5° to the west. About 40 ft. below the base is the coal-seam being mined by the Hikurangi Coal Company not far away. Probably some millions of tons of first-class limestone are available here, and, though it may be considered vandalism to destroy so beautiful a hill, the process of removing it has already begun. For some years past Mr. Reyburn has been quarrying stone from several faces at the south end and calcining it in kilns. Within the last two or three years he has also installed a pulverizing plant. According to Mr. M. Ongley, Assistant Geologist, who has furnished a brief report, the three kilns are each 20 ft. deep, with a diameter of 6 ft., and together turn out about 15 tons of lime per day. For this output 26 or 27 tons of limestone must be quarried. The pulverizing plant is driven by a traction-engine of about 10 horse-power, and consists of a rock-breaker made by Messrs. A. and G. Price (Thames), which reduces the large lumps of stone to about 1 in. cube, and a fine grinder which can pulverize about 1 ton per hour.

The Dominion Cement Company about 1916 began to quarry limestone at the north end of the hill, where it has opened several faces. The stone is railed to Whangarei, whence it is taken by water to the company's works at Mangapai. It is there used for the purpose of raising the lime content of the hydraulic limestone to the right tenor for cement-manufacture.

A sample of Waro limestone taken by Mr. Ongley in January, 1917, from a face of brownish stone with thin layers of tufaceous matter 1 in. apart, was found on analysis to contain 95·5 per cent of carbonate of lime.

The following analysis of limestone said to come from Hikurangi probably represents a sample obtained at Waro :—

Carbonate of lime ($CaCO_3$)	92·76
Carbonate of magnesia ($MgCO_3$)	2·96
Ferric oxide (Fe_2O_3)	1·01
Siliceous matters (sand, &c.)	2·67
Water	0·60
	100·00
Quicklime in calcined stone (per cent.) (Aston)	88

Reference.—Mottled-red compact crystalline limestone forwarded by Mr. R. Hobbs, M.H.R. Col. Mus. and Lab. 23rd Ann. Rep., 1889, p. 56. Lab. No. 4924.

According to S. H. Cox,* at or near Kaurihorehore (Kaurihohore) and not far from Kamo is a small patch of crystalline limestone, similar to the Waro limestone, and, like it, weathered into fantastic shapes. The name of "Abbey Rocks," frequently used in old Geological Survey reports for this outcrop, seems properly to belong to the limestone outcrops near Awaroa Creek (see below). At the time of Cox's visit (1877) a lime-kiln had been erected here, but apparently was only spasmodically used.

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* Rep. of Geol. Explor. during 1876–77, No. 10, 1877, p. 101.

The following analyses show that the Kamo limestone varies in quality. The samples were forwarded as likely material for cement, and may not be altogether representative.

	(1)	(2)	(3)
Carbonate of lime ($CaCO_3$)	92·83	76·47	88·62
Carbonate of magnesia ($MgCO_3$)	1·42	1·64	2·36
Alumina (Al_2O_3)	3·64	5·96	2·39
Iron oxides (FeO and Fe_2O_3)	Traces		
Soluble silica	0·10	0·63	0·43
Siliceous matters	2·01	14·68	5·80
Water	Traces	0·62	0·40
	100·00	100·00	100·00
Quicklime in calcined stone (per cent.)	88	65·1	81·9

Reference.—Forwarded by Mr. Decimus Atkinson. Col. Mus. and Lab. 17th Ann. Rep., 1882, p. 30. Lab. Nos. 3144/1, 2, 3. The analyst remarks: "The siliceous matters are, in the case of No. 2 and No. 3, mainly sand, generally coarse (some of which is mica)."

In 1914 Mr. H. Lilley forwarded two samples of calcareous rock from Kamo to the Dominion Laboratory. One of these was a rather poor limestone, analysing—Matter insoluble in acid, 20·25 per cent.; alumina and iron oxides, 1·60 per cent.; calcium carbonate, 77·47 per cent.; magnesium carbonate and undetermined, 0·68 per cent. The other sample was a siliceous rock with 10·88 per cent. of calcium carbonate. (See 48th Ann. Rep., 1915, p. 21. Lab. Nos. 919/1, 2.)

The Abbey Rocks, about three miles east of Whangarei as the crow flies, consist of crystalline (Whangarei) limestone. The outcrops are in or on the side of a valley, but stand well above the surrounding ground, and erosion along joint-planes, &c., has carved them into massive buttresses and pinnacles, whence the name of "Abbey Rocks." Numerous large recesses, caves, and underground passages have also been formed in the limestone. The rock is mostly white or greyish-white in colour, and for the most part is high in carbonate of lime. In places it contains thin bands of siliceous material. Outcrops of limestone cover many acres, and probably several millions of tons can be quarried here without difficulty. From the south end of the limestone area to tide-water in Awaroa Creek is about a mile, on an easy grade, so that transport facilities are good.

Samples of limestone taken by P. G. Morgan in January, 1915, were analysed at the Dominion Laboratory with the following result:—

	(1)	(2)
Insoluble in acid	7·07	1·74
Calcium carbonate	88·79	92·54
Phosphoric anhydride	0·20	0·11

References.—(1) Greyish limestone. (2) White limestone. Lab. Nos., F 122 and F 123.

The following statement by Cox is understood to refer to the Abbey Rocks limestone: "Overlying the brown and green sandstones to the east of Mr. Dent's house the limestones before described are again seen, and they occur here over a somewhat larger area than is the case with most of these outliers. They extend from the point where first seen on the slopes of Mount Parihaki to the Whareora caves overlooking the Whareora Valley, where coal occurs. These caves are, I understand, very fine . . . The dip of the limestones here is W.S.W., at an angle of 25°."* Whareora is a locality some distance to the north-east of the Abbey Rocks, where coal used to be mined.

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* *Loc. cit.*, p. 102.

Many years ago one or more bores was drilled south of the Abbey Rocks, in search of coal. Cox quotes the logs of four bores put down somewhere in this neighbourhood, and No. 3 of these entered 14 ft. of "limestone conglomerate" at a depth of 49 ft. 7 in., below which was 21 ft. of white and blue limestone.* Cox interprets this result as indicating a second limestone below the upper crystalline limestone, and on it he relies in part for his opinion that the hydraulic limestone underlies the crystalline limestone. It is, however, probable that faulting is present, as suggested by the presence of "ironstone conglomerate" and "limestone conglomerate" in the bore, and that whether Cox's conclusion be right or wrong his premises are open to suspicion.

Limestone, regarded by Cox† as the lower or hydraulic limestone, occurs over a small area on the south-east side of McLeod's Bay, and is there overlain by green sandstone. The accompanying strata, according to Cox, dip at an angle of 5° to the north-east. The hydraulic limestone, he also states, is seen again to the north-west at the very head of Parua Bay, where it is overlain by calcareous sandstone and black marl. His map also shows a small patch of the lower limestone in Limekiln or Tauri Kura Bay, south-east of Whangarei Heads.

Mr. J. C. Neill, in an unpublished report on the cement industry of New Zealand written in 1909, states that the argillaceous limestone or cement rock at Tauri Kura Bay is similar to that on Limestone Island (described later). It occupies an area of 19 acres (or more), surrounded by lava-flows, and partly covered by clays derived from weathered volcanic tuffs. In 1909 it was being quarried by J. J. Craig and Co. at a point close to deep water. The rock was burnt on the spot in ordinary brick-lined vertical kilns, the output of burnt rock being about 100 tons per week. This would require, of course, the quarrying of a much greater weight of limestone. The kiln-product was shipped to Auckland, where it was crushed to a fine powder and sold under the name of "hydraulic lime." Mr. Neill records that shells were also being burnt at Tauri Kura Bay in order to make pure hydrated (or slaked) lime, which was bagged and shipped to Auckland.

The following analyses of limestone from Whangarei Heads may here be quoted :—

	(1)	(2)
Silica (SiO_2)	13·50	16·52
Alumina (Al_2O_3)	2·30	3·16
Iron oxides (FeO and Fe_2O_3)		1·60
Lime (CaO)	45·40	42·81
Magnesia (MgO)	1·24	0·56
Carbonic anhydride (CO_2)	34·20	33·62
Moisture and organic matter	2·60	1·04
	99·24	99·31

Sample No. 1 contains approximately 77·43 per cent. of calcium carbonate, and No. 2 76·43 per cent.

References.—(1) Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 318. Contributor, J. Harrison.

(2) Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. No. F 605. Contributor, J. J. Craig (Limited).

A sample of limestone, forwarded from Parua Bay to the Dominion Laboratory by Mr. T. Blood in 1916, was found to contain 66 per cent. of calcium carbonate (50th Ann. Rep., 1917, p. 21. Lab. No. G 1396.)

Marshall‡ in his paper of 1916 mentions a sample of limestone from Horahora, Whangarei, which is very similar to the Waiomio limestone, but contains less glauconite. Horahora is a district near the coast, south of the Ngunguru River, and this presumably is the locality from which Dr. Marshall obtained his sample.

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* *Loc. cit.*, pp. 102–3. See also R. B. Denniston, pp. 129–30 of same publication.

† *Loc. cit.*, pp. 103, 104.

‡ *Loc. cit.*, p. 91, and plate ix, fig. 2 (same publication).

Mr. J. C. Neill in his unpublished report on the cement industry mentions a small area (4 acres) of 'white" or Whangarei limestone at Hewlett's Point, on the mainland south of Limestone Island. Analyses of this limestone made by the New Zealand Portland Cement Company are—

	(1)	(2)	(3)
Siliceous matter	4·8	3·7	4·5
Alumina and iron oxides	1·2	1·1	1·1
Calcium carbonate	91·2	94·4	92·4
Magnesium carbonate, &c.	..	..	2·0
Alkalies and water	1·9	..	
	99·1	99·2	100·0

No. 3 is quoted from F. N. Rhodes, Trans. Aust. Inst. Min. Eng., vol. 16, 1912, p. 277

There is also a small area of Whangarei limestone at Te Mata Point, Mangapai River. The crystalline limestone is poorly exposed in Whauwhau Creek at a point about a mile and a half north of Whangarei. Cox* states that it is a banded limestone, from which a few specimens of corals, echinoderms, and fossilized fish have been obtained. A specimen of fossil fish from this locality is now in the Auckland Museum. At the time of Cox's visit limestone from Whauwhau Creek was being burnt in kilns erected by the side of the harbour, but these have long since disappeared. A mile or two west of Whangarei, on the south side of the road in that direction, crystalline limestone forms a low ridge for some distance. No analyses of stone from this locality or from Whauwhau have been recorded.

Limestone Island, in Whangarei Harbour, is composed almost wholly of the argillaceous or hydraulic limestone. It is of such quality as to be almost perfect for the manufacture of cement, but for this purpose requires the admixture of a small amount of purer limestone. The situation—close to deep water—is also ideal. As is well known, the rock is extensively mined by the New Zealand Portland Cement Company, which has its works on the island.

The rock-outcrops on Limestone Island are described by Cox as follows: " At the northern end of the island the beds, which are here dipping to the north-east at somewhat various angles, averaging about 30°, consist of marly limestones much laminated in character; and as we pass to the southward we find a bed of greensand interstratified with them, while on the extreme southern end of the island flaggy limestones occur, with a dip slightly less than that given above, but representing the lowest member of the calcareous beds, which, as a body, dip below the sandstone, &c., on the mainland to the north of the harbour."

Mr. J. C. Neill, in the unpublished report on the cement industry of New Zealand already mentioned, describes the rocks of Limestone Island and other localities where argillaceous limestone occurs. His remarks, slightly summarized, are as follow:—

" The principal rock of Limestone Island is a fine-grained argillaceous limestone. It is overlain by a green calcareous sandstone grading into green sandy limestone. On the shore of the mainland to the west the cement rock may be seen overlain conformably by a considerable thickness of green calcareous sandstone containing from 30 to 80 per cent. of calcium carbonate. Here also the lower exposure of the cement rock may be seen grading into green calcareous sandstone, which in turn passes into a subcrystalline limestone containing glauconitic layers. These latter beds at Tokitoki Point are in contact with crystalline shelly and pebbly limestone, in apparent unconformity.

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* *Loc. cit.*, p. 101.

"The main mass of Tikorangi Hill to the west appears to be composed of cement rock, overlain by green calcareous sandstone. The cement rock disappears below sandstones to the north and west, and no further outcrops of it are known in the locality. At Grahamtown or Onerahi, half a mile east of Limestone Island, the cement rock outcrops on the beach, but no great thickness can be seen above high-water mark. It is overlain by green calcareous sandstone and by lava-flows.

"The cement rock wherever exposed is much broken and contorted. It is irregularly penetrated by nearly vertical stringers of calcite varying in thickness from a thread to several inches. There are also several thin vertical seams of green calcareous sand carrying about 40 per cent. of calcium carbonate.

"Limestone Island has an area of 93 acres, and rises to 212 ft. above sea-level. It is estimated to contain 30,000,000 tons of workable cement rock above high-water mark. Mount Tikorangi shows an enormous amount of cement rock which could be quarried very cheaply, but is rather far from deep water.

"The argillaceous limestone of Limestone Island is a fine-grained fairly hard rock, varying in colour from nearly white to a dark bluish-grey. It is entirely free from sand or grit. The white parts of the rock are those subjected to weathering, which, curiously enough, extracts the argillaceous elements in preference to the lime, so that the nearer the outcrop the higher is the percentage of lime."*

The following analyses of argillaceous rock from Limestone Island are available:—

	(1)	(2)	(3)	(4)	(5)	(6)
Carbonate of lime	78·93	62·40	80·29	63·63	68·53	58·91
Carbonate of magnesia ..	1·89	2·16	2·42	2·14	1·64	1·82
Alumina and iron oxides ..	3·01	8·41	4·64	7·60	5·41	7·41
Siliceous matter, principally clay	15·79	26·32	12·26	25·99	24·02	31·40
Water	0·38	0·71	0·39	0·64	0·40	0·46
	100·00	100·00	100·00	100·00	100·00	100·00

Reference.—Collected by Mr. Decimus Atkinson. Col. Mus. and Lab. 17th Ann. Rep., 1882, p. 28. Lab. Nos. 3063/1–6.

The following five analyses were supplied by the New Zealand Portland Cement Company in 1909, and are quoted by Mr. Neill in his report of that year. Nos. 1 and 2 are typical control analyses made at the works; No. 3 represents the poorer grade of rock, and Nos. 4 and 5 the ordinary grade.

	(1)	(2)	(3)	(4)	(5)
Siliceous matter	26·5	21·4	24·9	19·8	19·8
Carbonate of lime ($CaCO_3$) ..	67·1	73·3	70·6	77·6	74·2
Iron oxides (FeO, Fe_2O_3) ..	1·5	1·6	1·0	1·2	1·0
Alumina (Al_2O_3)			1·6	1·0	1·4
Magnesia (MgO)	5·1	4·2	Traces	Traces	0·3
Alkalies and water			..	..	..
Loss on ignition	..	..	3·1	2·7	2·5
	100·2	100·5	101·2	102·3	99·2

F. N. Rhodes, in Trans. Aust. Inst. Min. Eng., vol. 16, 1912, p. 277, quotes No. 5 above, and three other analyses of cement rock showing 67·6 per cent., 72·9 per cent., and 70·1 per cent. of calcium carbonate (not CaO as printed).

Limestone occurs in the Otaika district, a few miles south of Whangarei, although apparently only to a small extent. Argillaceous limestone has been found by boring in the Whangarei High School endowment between Kioreroa Railway-station and the tidal part of the Otaika River. The following analyses are available:—

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* Presumably the word "lime" in this sentence is intended to mean carbonate of lime. A similar raising of the carbonate content seems to take place with some soft or friable limestone deposits in the South Island. See 10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, p. 17.

	(1)
Insoluble matter	9·12
Alumina and iron oxides	1·70
Calcium carbonate	86·71
Moisture, &c.	3·22
	100·75

	(2)
Silica (SiO_2)	20·30
Alumina (Al_2O_3)	3·70
Iron oxide (Fe_2O_3)	1·80
Lime (CaO)	39·33
Magnesia (MgO)	1·03
Carbonic anhydride (CO_2)	30·90
Water and organic matter	2·30
Undetermined	0·64
	100·00
Calcium carbonate (by calculation) (per cent.)	67·75

References.—(1) B. C. Aston in the *Journal of Agriculture*, vol. 11, No. 3, Sept., 1915, p. 236. Approximate amount of lime (CaO) in calcined limestone, 81 per cent. Analyst's number, F 468. Date, 1905. (See also 13th Ann. Rep. Dept. Agri., Chemical Division, 1905, p. 84.) Forwarded by E. Sands (p. 88).

(2) Cement-stone from No. 2 borehole, Kioreroa (not Kioreora) Syndicate's property. Dom. Lab. 45th Ann. Rep., 1912, p. 14. Lab. No. B 181. Calcined rock would contain 58·88 per cent. of lime (CaO).

South of Otaika, on the road towards Tikorangi Hill, is an old limestone quarry that has been worked for roadmaking material. No analysis of the rock has been made. On the road to the Dominion Company's works is a quarry where a hard glauconitic sandstone with almost horizontal bedding-planes has been worked for a similar purpose. Argillaceous limestone conformably underlies.

According to a geological map by Cox* an area over four miles long with an extreme breadth of over two miles, south of Ruakaka River and north-west of Waipu, is formed of Whangarei limestone. No other information concerning this area has been obtained.

South of the mouth of Waipu River, at and near The Cove, is a small area where limestone, said to rest unconformably on greensands, occurs. There are caves about eight miles from Waipu, known as Morrison's. According to Cox they contain some splendid stalactites and stalagmites. Analyses of limestone from Waipu are as follow:—

	(1)	(2)
Insoluble matter, (sand, &c.)	4·26	6·64
Alumina and iron oxides	2·27	1·80
Calcium carbonate ($CaCO_3$)	91·63	90·04
Magnesium carbonate ($MgCO_3$)	0·92	1·52
Moisture	0·92	
Undetermined	..	
	100·00	100·00
Quicklime in calcined stone (per cent.) (Aston)	86	83

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* Rep. of Geol. Explor. during 1879–80, No. 13, 1881, opposite p. 28.

References.—(1) Aston, B. C., in the *Journal of Agriculture*, vol. 11, No. 3, Sept., 1915, p. 236. Analyst's number, F 227. Date, 1905. Quicklime (CaO) in calcined stone is approximately 86 per cent. (See also 13th Ann. Rep. Dept. Agric., Chemical Division, 1905, p. 84.) The sample was forwarded by Gus McKay (p. 85). Four other samples (E 170–73, date 1904) are quoted as containing the following percentages of calcium carbonate: 85·72, 89·30, 79·29, and 76·97. (See also 12th Ann. Rep. Dept. Agric., Chemical Division, 1904, p. 143.) The samples were forwarded by the Secretary for Agriculture (p. 150).

(2) Forwarded by R. R. McKay. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. No. E 513. Quicklime (CaO) in calcined stone approximately 83 per cent.

Limestone occurs in the western part of Whangarei County, but little is known as to its extent and quality.

The following analyses of samples from Parakao, Mangakahia, and Maungakaramea are available:—

	(1)	(2)	(3)	(4)	(5)
Matter insoluble in acid	..	..	..	33·35	8·21
Alumina and iron oxides	..	..	..	..	4·20
Calcium carbonate ($CaCO_3$)	85·55	77·00	81·50	55·52	84·34
Magnesium carbonate ($MgCO_3$)	..	..	..	..	2·99
Phosphoric anhydride (P_2O_5)	..	..	..	0·17	0·26
Water	..	..	..	..	..
	..	..	..	89·04	100·00

References.—(1) Forwarded by W. Ruddell from Parakao. Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 508.

(2) (3) Forwarded by H. R. Ruddell from Parakao. Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. Nos. G 352/1 and G 352/2.

(4) Soft grey sandy limestone from Mangakahia district, per Major G. Clark-Walker. 9th Ann. Rep. N.Z. Geol. Surv., Appendix C of Parl. Paper C.–2, 1915, p. 88. Analysis made in Dominion Laboratory. Lab. No. F 115.

(5) Forwarded from Maungakaramea by Mr. C. E. Hayward. Col. Mus. and Lab. 26th Ann. Rep., 1892, p. 29. Lab. No. 5741. The analyst (W. Skey) remarks that the sample is a close coherent light-coloured limestone, well adapted for building purposes if it can be obtained in fair-sized blocks, and is also suitable for burning into lime if carefully selected.

The following analyses ascribed to Whangarei, but perhaps representing samples taken some distance from that town, may be given here:—

(1) "Limestone" with 40·8 per cent. of carbonate of lime, and (2) limestone with 75·7 per cent., from Whangarei, forwarded by Mr. Kelly, M.H.R. Col. Mus. and Lab. 14th Ann. Rep., 1879, p. 25. Lab. Nos. 2377/1, 2.

	(3)	(4)	(5)
Silica	25·67	21·28	24·25
Alumina	2·98	2·14	3·80
Iron oxide	1·76	1·32	2·30
Lime	35·68	39·07	36·21
Magnesia	1·26	0·92	1·08
*Carbonic anhydride	28·16	29·80	28·45
Water and organic matter	2·63	3·78	2·83
Alkalies and undetermined	1·86	1·69	1·08
	100·00	100·00	100·00
*Equivalent to carbonate of lime (per cent.)	64·00	67·73	64·66
Quicklime (CaO) in calcined stone (per cent.)	51·56	58·80	52·69

References.—(3) (4) Hydraulic limestone from near Whangarei, forwarded by George White. Dom. Lab. 45th Ann. Rep., 1912, p. 16. Lab. Nos. B 1027/1, 2.

(5) From near Whangarei, forwarded by J. Harrison. Same publication as Nos. 3 and 4, p. 20. Lab. No. B 157.

Summary of Limestone Resources and of Means of Transport.

Whangarei County has great limestone resources, and in this respect is one of the most fortunate districts in New Zealand. Not only has it numerous deposits of high-grade stone suitable for calcination, but it has immense quantities of argillaceous limestone suitable for application to the soil after pulverization, and eminently adapted for the manufacture of cement. Many of the deposits are close to a railway or to deep water, and, if necessary, lime for agricultural purposes can conveniently be railed (after the completion of the North Auckland Railway) or shipped to other counties. The fine harbour of Whangarei affords good sea communications, and at the same time reaches far into the land. North of Bream Head there are other harbours, usable by small steamers. A railway runs from Onerahi, the port of Whangarei, through the town of Whangarei to Opua, in Bay of Islands County. A railway from Whangarei to Dargaville is projected, and will ultimately connect with the North Auckland Railway. Thus Whangarei County will some day be connected by rail with Hokianga, Auckland, and the southern parts of the North Island. Until the county is better roaded the distribution of lime and other heavy goods will be impeded; but the roads, as in most parts of New Zealand, are being continuously improved, and in a few years all important highways will be macadamized. The volcanic rocks and hard limestones of the county are good roadmaking materials.

Literature.

The chief references to the geology and limestone of Whangarei County are the following :—

Rep. of Geol. Explor., No. 10, 1877, pp. xii-xv, 95–106, 128–35; No. 16, 1884, pp. 110–22 (Whangarei limestone p. 115, Limestone Island p. 117); No. 21, 1892, pp. 177–78; No. 22, 1894, pp. 55–69.

Thorne, G., jun.: "Notes on the Discovery of Moa and Moa-hunters' Remains at Pataua River, near Whangarei." Trans. N.Z. Inst., vol. 8, 1876, pp. 83–94. Describes the sandhills along the coast from Bream Head to Horahora River. On the south bank of the Pataua River "pipi-shells form a perpendicular little cliff . . . fifteen feet high."

Park, James: "The Geology of New Zealand," 1910. See pages indexed under heading of "Whangarei."

Rhodes, F. N.: "Plant and Method of Manufacture of Portland Cement at Limestone Island." Trans. Aust. Inst. Min. Eng., vol. 16, 1912, pp. 197–209.

Morgan, P. G.: 9th Ann. Rep. N.Z. Geol. Surv., App. C of C.–2, 1915, pp. 87–88.

Marshall, P.: "The Younger Limestones of New Zealand." Trans. N.Z. Inst., vol. 48, 1916, pp. 87–99 (see especially 87–89, 91, 92, 93–94, &c.).

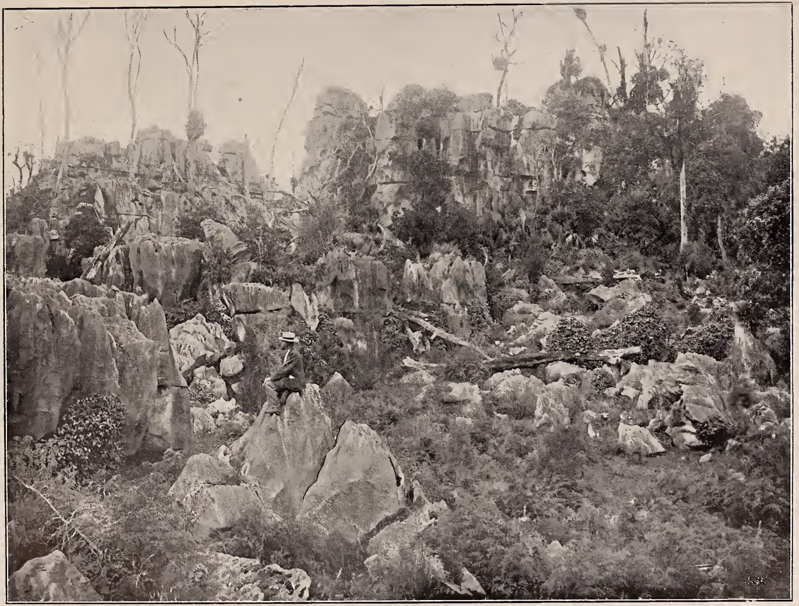
Marshall, P.: "Geology of the Central Kaipara." Trans. N.Z. Inst., vol. 49, 1917, pp. 433–50. This paper, *inter alia*, discusses the age of the Whangarei limestone (see p. 434, &c.).

Cotton, C. A.: "New Zealand's Niagara." *N.Z. Journal of Science and Technology*, vol. 1, No. 1, January, 1918, pp. 9–11. Describes Wairua Falls.

6. HOBSON COUNTY.

Hobson County consists of a compact area having Dargaville as its centre, together with the peninsula on the western side of the northern part of Kaipara Harbour. Much of the county has excellent water carriage, provided by the Wairoa River and its tributaries. Limestone outcrops at or near Mangawhare (a suburb of Dargaville), Mititai, Arapohue, and Avoca. In general it occurs as somewhat poorly exposed bands with steep dip in the district east of the Wairoa River from Tokatoka to Tangowahine. Little or nothing,

PLATE II



Limestone Rocks near Kamo, Whangarei County

[*Photo by Tourist Department.*]

however, is known about limestone in the northern and eastern parts of the county. According to Cox's report of 1881 limestone occurs north of Dargaville, at Tutamoe near Dargaville, north of Tokatoka Hill, from the flanks of Mangarahu Hill to Arapohue, &c. (pages 34, 35, 36).

Mr. Ongley, Assistant Geologist, visited some of the limestone outcrops of Hobson County in January, 1917. At Avoca, six miles from Tangowahine, he reports that limestone was being quarried for roadmaking purposes at a point roughly 95 ft. above sea-level. The stone was compact, of brownish colour, and contained layers and scattered grains of greensand. The Avoca Quarry showed a 40 ft. face of stone, capped by thin soil. The strike was south-south-eastward (165°), and the dip 24° to the south of west. The rock was easily quarried. A sample of crystalline appearance, and probably of better quality than the average, taken by Mr. Ongley was found in the Dominion Laboratory to contain 92 per cent. of calcium carbonate. (Lab. No. H 322/23.)

Blake's Quarry is on the Tangowahine–Avoca Road, four miles from Tangowahine, and about 45 ft. above sea-level. The face is 20 yards long, and shows 25 ft. of shattered argillaceous limestone, capped by about 1 ft. of soil. No strike or dip could be obtained, the bedding-planes being indistinguishable. The rock is quarried for roadmaking. A sample of the stone tested in the Dominion Laboratory yielded 78 per cent. of carbonate of lime (Lab. No. H 322/24).

Between Avoca and Blake's Quarry there are numerous road-cuttings in limestone, so that evidently large supplies of easily quarried limestone may be obtained in the district. Analyses of representative samples are required in order to ascertain the quality.

The hills near the Mititai–Arapohue Road are of argillaceous limestone, and Mr. Ongley states that quarries have been opened in five places at heights of 250 ft. to 300 ft. above sea-level. Limestone with a thin covering of soil extends for two miles along the road. It is a fine-grained, chalky, shattered, slickensided rock with numerous calcite veins, and the bedding-planes are either indistinguishable or stand nearly vertical. The stone, which is easily quarried, is used for making roads. Three samples taken by Mr. Ongley from different quarries are very similar in composition. The Dominion Analyst (Dr. J. S. Maclaurin) reports one as containing 77 per cent. of carbonate of lime, and the other two as each yielding 76 per cent. (Lab. Nos. H 322/21–23.)

The limestone on the road from Arapohue to Tokatoka is similar to that on the Mititai Road. A sample taken by Mr. Ongley on this road was argillaceous limestone of light colour. It yielded on analysis 74 per cent. of calcium carbonate. (Lab. No. H 322/19.)

The following further analyses of limestone from Hobson County are available:—

	(1)	(2)	(3)
Matter insoluble in acid	20·30	..	19·05
Iron oxides and alumina	..	..	2·34
Calcium carbonate	73·90	65·45	75·95
Magnesium carbonate	1·70	..	2·66
Water	4·10	..	
Undetermined	..	..	
	100·00	..	100·00
Quicklime in calcined stone (per cent.)	..	..	64

References.—(1) Hydraulic limestone from Mangawhare, near Dargaville. Col. Mus. and Lab. 22nd Ann. Rep., 1887, p. 44. Lab. No. 4397.

(2) From Mitiai (? Mititai), forwarded by A. G. Thompson, per Secretary of Agriculture. Dom. Lab. 45th Ann. Rep., p. 20. Lab. No. B 532. Phosphoric anhydride, 0·13 per cent.

(3) From Arapohue, forwarded by A. J. Gelston. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 1176.

Hector and Skey, in their report of 1866 quoted on page 37, mention a limestone from "Wairoa, Auckland," which contained 95·47 per cent. of calcium carbonate. (See also appendix to Chapter III of this bulletin.)

All the limestone reported from Hobson County* appears to be similar in appearance and age to the so-called hydraulic limestone of Whangarei and other North Auckland counties. If this correlation is correct, and if the more generally accepted view of the relative ages of the two limestones is correct, the crystalline or Whangarei limestone ought to outcrop at a lower horizon than the hydraulic limestone, and not far below it. If the opposing view maintained by Cox in 1877 and Park in 1910 is correct, then the crystalline Whangarei limestone may not be present, but, if present, will be found at a higher horizon than the hydraulic or argillaceous limestone. Since in the Whangarei district the crystalline limestone is of high grade, it may be expected (although not with certainty) that if present on the west side of North Auckland Peninsula it will also be of good quality.

Summary of Limestone Resources and of Means of Transport.

Apparently Hobson County is moderately well supplied with limestone suitable for use by agriculturists after it has been pulverized. High-grade limestone may be scarce. The Wairoa River and its tributaries afford good means of transport into many parts of the county. A railway from Dargaville to Kaihu has been in existence for many years. When the North Auckland Railway reaches Dargaville, and the projected line to Whangarei is made, the county will have good means of communication. By that time various roads now in the making will, no doubt, be completed.

Literature.

The literature dealing with the geology of Hobson County is scanty. The following are the chief references :—

Rep. of Geol. Explor., No. 13, 1881, parts of pp. 13–39 (S. H. Cox), especially pp. 15, 22, 23 (Tokatoka), 34, 35, 36. Localities in the county are more or less incidentally mentioned in Nos. 9 (1877), 19 (1888), and 21 (1892). A brief account of its geology is given in No. 21, p. 154.

The following paper gives a good account of the Wairoa River: Mulgan, E. K.: "The Northern Wairoa." Trans. N.Z. Inst., vol. 36, 1904, pp. 453–64. On p. 459 calcareous marl below alluvial deposits at Raupo (Otamatea County) is mentioned. On p. 460 reference is made to argillaceous limestone at Mangawhare, Arapohue, and Okahu.

7. OTAMATEA COUNTY.

Much has been written about the geology of Otamatea and the adjoining Rodney County, and many important points have yet to be settled. The chief references are cited on a following page.

The geological formation in which the hydraulic limestone occurs is very well represented in Otamatea County, and it may be said that more or less of that limestone occurs in almost every part of the county. Hard limestone of good grade similar to the Whangarei limestone occurs in one or two localities, notably between Pahi and Paparoa.

According to Cox, chalk marls and hydraulic limestones extend six miles from Tokatoka Hill in the direction of Matakohe (1881 report, p. 35). In 1915 the Raupo Farmers' Union sent two samples of limestone from Ruawai (east bank of Northern Wairoa River, a few miles south of Tokatoka) to the Dominion Laboratory. The analyses quoted below show that somewhere in this locality high-grade limestone suitable for " burning " occurs. The samples analysed may possibly have come from bands of purer limestone in or below the hydraulic limestone, similar to those mentioned later as occurring south of Captain Colbeck's, Pahi Estuary.

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* Except that at Avoca, described on previous page.

	(1)	(2)
Matter insoluble in acid	9·71	2·96
Alumina and iron oxides	2·12	0·90
Calcium carbonate ($CaCO_3$)	87·79	96·03
Magnesium carbonate and undetermined	0·38	0·11
	100·00	100·00
Yield of quicklime in calcined stone (per cent.) ..	80	93

Reference.—Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. Nos. E 159/1, 2.

Some of the cuttings on the railway-line near Maungaturoto, beyond Bickerstaffe Railway-station, pass through bands of argillaceous limestone, but on the whole a calcareous claystone predominates. This rock is very liable to slump, and gives rise to a subdued type of topography, with few steep slopes and few rock outcrops, except those produced by artificial means. The following analyses may here be quoted :—

	(1)	(2)	(3)	(4)	(5)
Matter insoluble in acid	14·70	7·46	5·18	20·95	15·61
Alumina and iron oxides.. ..	1·10	1·67	0·90	1·50	..
Calcium carbonate ($CaCO_3$) ..	80·76	88·00	92·86	74·25	78·86
Magnesium carbonate, &c. ..	1·14	0·86	..	..	..
Moisture, &c.	2·30	2·01	1·06	3·30	..
	100·00	100·00	100·00	100·00	..
Approximate yield of quicklime in calcined limestone (per cent.)	73	83	89	65	68

References. — (1) Aston, B. C.: Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 237. Analyst's number, E 310. Date, 1904. From Bickerstaffe, Whakapirau.

(2) (3) (4) Same locality and reference as (1). Analyst's numbers, F 186, F 187, F 188. Date, 1905.

(5) Morgan, P. G.: 9th Ann. Rep. N.Z. Geol. Surv., App. C. of Parl. Paper C.–2, 1915, p. 88. Impure (argillaceous) limestone from railway-cuttings south-west of Maungaturoto, beyond tunnel. Phosphoric anhydride, 0·10 per cent. Lab. No. F 112.

During a visit to the Maungaturoto district in January, 1915, one of the writers (P. G. Morgan) saw no limestone approaching the grade of analyses Nos. 2 and 3 above, except thin calcite veins in the argillaceous limestone. It would be interesting to know exactly where these samples were obtained. If the locality were a new one, and the limestone occurred in quantity, the information would be valuable. It may be as well to remark that the stones represented by analyses Nos. 1, 4, and 5 probably could not be satisfactorily calcined. They would most likely form hard clinkers that would require to be pulverized before they could be used for agricultural purposes. Near the railway-line north of the road between Maungaturoto and Paparoa is a quarry where impure limestone was being quarried in 1915 for railway purposes. The rock is nearly white in colour, and somewhat arenaceous-looking. The following part-analysis of a sample collected in January, 1915, by P. G. Morgan does not reveal its composition very clearly, one-third of the constituents not being determined :—

	Per Cent.
Matter insoluble in acid	17·02
Calcium carbonate ($CaCO_3$)	49·45
Phosphoric anhydride (P_2O_5)	0·14

Reference.—Same reference as No. 5 from Maungaturoto (see above). Lab. No. F 113.

The well-known Gibraltar Rocks are on the Pahi River, or rather estuary, a short distance above the point where it becomes narrow and river-like. They are bluffs consisting of more or less glauconitic crystalline limestone, apparently grading into sandy limestone or calcareous sandstone. The strike is to the north-west, and the dip probably about 85° to the south-west. Some distance down the river or estuary, along its eastern shore southward from the landing formerly used by Captain Colbeck, are four or five bands of similar limestone, interbedded with greenish claystone, greensand, and in one case argillaceous or hydraulic limestone. These bands are from 10 ft. to 20 ft. thick. Their strike and dip are erratic, but in general the strike is to the north-west, and the dip is to the south-west at angles of from 55° upwards. All these beds are apparently overlain to the southward by the main body of the hydraulic limestone. It is clear that important faults are present, complicating the geological structure, and outcrops are anything but continuous, so that the diversity of opinion among geologists concerning the stratigraphy of the Pahi district is not to be wondered at.

Crystalline limestone forms Skelton's Hill, which is not marked on the maps consulted, but appears to be somewhere on Pahi Peninsula to the north of Captain Colbeck's former residence. Similar limestone occurs also in other hills between Pahi Estuary and Paparoa. (Cox, 1882, p. 23.)

The following analyses of samples collected by P. G. Morgan in September, 1915, show that the limestones of Gibraltar Rocks and of the bands south of Colbeck's Landing are of good quality :—

	(1)	(2)
Insoluble in acid	3·13	7·05
Alumina and iron oxides (Al_2O_3, Fe_2O_3)	1·75	1·25
Lime (CaO)	51·92	50·14
Magnesia (MgO)	0·77	1·16
Phosphoric anhydride (P_2O_5)	0·12	0·27
Carbonic anhydride (CO_2)	41·20	39·08
Water and organic matter	1·29	1·42
	100·18	100·37
Calcium carbonate (approximate percentage) ..	91·71	85·92
Approximate yield of calcium oxide or quicklime (CaO) in calcined limestone (per cent.)	90·0	83·7

References.—(1) Yellowish-white limestone from Gibraltar Rocks. Morgan, P. G.: 10th Ann. Rep. N.Z. Geol. Surv., 1916, Parl. Paper C.–2B, p. 12; and Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. No. F 1121.

(2) Hard light-coloured limestone from band in beds on east side of Pahi Estuary below Colbeck's. Same references as (1). Lab. No. F 1122.

Owing to the importance of the problems connected with the geology of the Pahi and neighbouring districts, the following special references will here be given :—

Cox, S. H.: "Geology of the Rodney and Marsden Counties." Rep. of Geol. Explor. during 1879–80, No. 13, 1881, pp. 13–39 (see pp. 17, 18, 19, 33, 35, and map opposite p. 28).

Cox, S. H.: "North Auckland District . . ." Rep. of Geol. Explor. during 1881, No. 14, 1882, pp. 17–41 (see pp. 23–24).

Park, James: "On the Kaipara District." Rep. of Geol. Explor. during 1885, No. 17, 1886, pp. 164–70.

Park, James: "Kaipara and Wade Districts." Rep. of Geol. Explor. during 1886–87, No. 18, 1887, pp. 219–33 (see especially pp. 220–22, 228, 229).

McKay, Alex.: "On the Geology of the Northern District of Auckland." Rep. of Geol. Explor. during 1886–87, No. 19, 1888, pp. 37–57 (see especially pp. 53–54).

Morgan, P. G.: Publication quoted above, pp. 11, 12, 13.

Marshall, P.: "The Younger Limestones of New Zealand." Trans. N.Z. Inst., vol. 48, 1916, pp. 87–99 (see pp. 87, 88, 89, 91, &c.)

Marshall, P.: "Geology of the Central Kaipara." Trans. N.Z. Inst., vol. 49, 1917, pp. 433–50.

Marshall, P.: "The Tertiary Molluscan Fauna of Pakaurangi Point, Kaipara Harbour." Trans. N.Z. Inst., vol. 50, 1918, pp. 263–78.

At Pakaurangi Point, which forms the south-east corner of Komiti Peninsula, is a bed composed almost wholly of foraminiferal remains. It is called by Park the "Orbitolite Limestone" (1886 report, p. 166), but according to Marshall the chief organism present is *Miogypsina* (paper of 1917, p. 437). Park also mentions a bed of shelly limestone 12 ft. thick, which occurs at Strawberry Bay, on the west side of Komiti Peninsula (1886 report, p. 167).

The argillaceous or hydraulic limestone so often mentioned on the preceding pages is developed on a most important scale on the shores of Kaipara Harbour from Matakohe south-eastward. According to the available descriptions and maps it covers a considerable area on Komiti Peninsula near Matakohe, and continues down the east side of the peninsula to near Pakaurangi Point. Hydraulic limestone occupies part of Pahi Peninsula, and is the prevailing rock on the east side of the Pahi and Arapaoa arms from some distance north of Jackman's to near the Otamatea Arm, where claystones appear. It forms a small bluff near Batley Wharf, and appears to form portions of the peninsula between the Otamatea and Oruawhero arms, whence it extends southward and eastward into Rodney County. In many places the hydraulic limestone is highly siliceous, and therefore not suitable either for agricultural purposes or for the manufacture of cement. Marshall draws special attention to this feature (1917 paper, pp. 440–41), but perhaps over-emphasizes it. There can be no doubt, however, that the western and southern parts of Otamatea County contain immense quantities of argillaceous limestone, more or less suitable for use in the manufacture of cement and (after being pulverized) as soil-dressings. Geological exploration and mapping in order to define the boundaries of the limestone areas are necessary. Hand-in-hand with this work should go extensive and careful sampling, so that a series of reliable analyses may be obtained. The following analyses probably all represent the hydraulic limestone in the western and southern parts of Otamatea County:—

	(1)	(2)
Carbonate of lime	73·16	89·09
Carbonate of magnesia	1·72	..
Alumina and iron oxides, soluble in acid used	1·24	..
Silica liberated by acid used	6·49	..
Clay	12·83	..
Water	4·12	..
Alkalies and loss	0·44	..
	100·00	..

References.—(1) Forwarded by Captain Colbeck from Kaipara district. Col. Mus. and Lab. 19th Ann. Rep., 1885, p. 28. Lab. No. 3727.

(2) From Pukekaroro, near Kaiwaka; forwarded by H. R. Cooke in 1914. Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab. No. E 534/1.

	(3)	(4)
Silica (SiO_2)	17·48	41·53
Alumina (Al_2O_3)	3·01	8·71
Iron oxide (Fe_2O_3)	1·61	2·48
Lime (CaO)	41·49	21·05
Magnesia (MgO)	0·78	1·31
Carbonic anhydride (CO_2)	32·00	15·74
Water and organic matter	3·03	8·40
Undetermined	0·00	0·78
	100·00	100·00

Reference.—Cement-stones from Kaipara, forwarded in 1911 by Hon. Minister of Mines on account of Heathcote Jackman. Dom. Lab. 45th Ann. Rep., 1912, pp. 14–15. Lab. Nos. B 282/1, 2.

The carbonic anhydride in No. 3 is equivalent to 72·73 per cent. of calcium carbonate, that in No. 4 to 35·77 per cent. If all the magnesia be supposed to be combined as carbonate, the percentages of calcium carbonate will be reduced to 70·8 and 32·5. The true percentages will be somewhat higher, no doubt, but not as high as indicated by the first result. No. 3 when burned would contain 63·87 per cent. of calcium oxide, part of which would be combined with other oxides. The percentage of free calcium oxide or quicklime would be 62 per cent. or a little less. No. 4 is not limestone, but, as judged by the analysis, a sandy calcareous claystone.

	(5)	(6)	(7)	(8)	(9)	(10)
Calcium carbonate ($CaCO_3$)	76·00	48·04	83·47	69·80	71·50	83·00
Phosphoric anhydride ..	..	0·13	0·08	..	..	..

References.—(5) Forwarded by F. Metcalfe from Matakohe. Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. No. G 117.

(6) Soft impure limestone forwarded to the Geological Survey in June, 1914, by J. Trewin from Te Opu, south of Marahemu. Dom. Lab. 48th Ann. Rep., 1915, p. 18. Lab. No. E 747.

(7) Forwarded by W. H. Jordan, and (8) (9) (10) forwarded by C. A. Jeffries, from Whakapirau. Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. Nos. G 45, G 83/1, 2, 3.

A sample from " Kaipara," forwarded in 1914 to the Dominion Laboratory by F. G. H. Walker, contained 29·40 per cent. of lime (CaO), equivalent to 52·5 per cent. of calcium carbonate and 0·15 per cent. of phosphoric anhydride. Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab. No. E 440.

Bands of limestone, similar to those seen on the east shore of Pahi Estuary below Colbeck's, appear to occur at Curtis Point, on the north side of the Otamatea Estuary near Batley. (Park, 1886 report, p. 169.) The limestone is described by Park as " gritty," but this term probably refers only to the texture ; it is similarly used by Marshall (1917 paper, p. 438).

There are said to be large deposits of shells in various parts of Kaipara Harbour, which could be delivered at any point on the shores of the harbour at a cost not exceeding 5s. to 7s. per cubic yard.

Summary of Limestone Resources and of Means of Transport.

As already stated, Otamatea County contains immense amounts of argillaceous limestone suitable, after being pulverized, for soil-dressing. It has also, at the Gibraltar Rocks and probably elsewhere, limestone suitable for calcination. The tidal arms of Kaipara Harbour give fair access for oil-launches to many parts of the county. Some of the smaller channels, however, are navigable only at or near high tide, and thus their use for transport purposes is often inconvenient. The North Auckland Railway now runs through the greater part of the county, and may be expected to assist greatly in the distribution of lime. With the completion of this railway and the improvement of the roads, which at present are poor, Otamatea County will be well supplied with means of communication. Stone suitable for roadmaking is not found everywhere, but on the whole the county is not badly supplied. Here and there are masses of igneous rock which might well be more utilized for roadmaking than they are at present—for example, the dacite of Pukekaroro Hill, four miles east of Kaiwaka.

Literature.

The reports and papers listed on pages 60–61 form the main part of the literature relating to Otamatea County.

8. RODNEY COUNTY AND KAWAU ISLAND.

On the south side of the Oruawhero Arm of the Kaipara Harbour, for some miles south-west of Port Albert, the hydraulic limestone is stated to be fairly well developed. Bands of the same rock occur near Wellsford Railway-station. From these two localities—Port Albert and Wellsford—a broad but gradually narrowing area containing many outcrops of hydraulic limestone extends to the mouth of the Hoteo River. Other rocks, however, especially calcareous or " chalky " claystones, occupy great parts of the area thus defined. In places calcite veins occur, but these are of no importance. Near Port Albert concretionary masses of limestone with the curious structure known as " cone-in-cone " are common. At Kaipara Flats there are various outcrops of argillaceous limestone associated with chalky claystone and flinty bands. An outcrop a few chains south-west of Mr. Thompson's house is said to have yielded stone from which good lime was made. In general the district surrounding Kaipara Flats, and thence westward and eastward to both coasts, is covered by a series of rocks younger than and unconformable to the series containing the hydraulic limestone. These rocks are calcareous, but not highly so. Shelly rock is reported to occur on Mr. Breese's land north of Kaipara Flats and east of the railway-line. The following analysis of limestone represents a sample of argillaceous limestone collected by P. G. Morgan in January, 1915, from a band in the railway-cutting 20 chains north of Kaipara Flats Railway-station. This yielded—

	Per Cent.
Matter insoluble in acid	17·62
Calcium carbonate	75·95
Phosphoric anhydride	0·08

Reference.—9th Ann. Rep. N.Z. Geol. Surv., Appendix C to Parl. Paper C.–2 (Mines Rep.), 1915, p. 88. Lab. No. F 129.

Recently B. C. Aston (Jour. Agric., vol. 17, No. 2, Aug., 1918, p. 99) has published nine analyses of calcareous rocks from Rodney County, most of which may probably be referred to the hydraulic limestone. The percentages of calcium carbonate are: 72·7, 78·8, 6·9, 79·9, 78·5, 71·6, 68·2, 46·4 (all from Wellsford); 74·0 (from Woodcock's). He also gives an analysis of high-grade stone, with 90·8 per cent. of $CaCO_3$, from the indefinite locality " Kaipara " (same publication, p. 100).

Near Warkworth, or Mahurangi as the locality is called in old reports, bands of marly glauconitic and blue limestone, associated with sandstones, shales, &c., outcrop in the bed of Palmer's Creek. The glauconitic limestone was at one time quarried for burning. According to J. C. Neill, in his unpublished report on the cement industry, a Mr. John Southgate about 1849 or 1850 began to make lime from the argillaceous limestone east of Warkworth, where the cement-works now are. In 1865 the plant was shifted to the north bank of the Mahurangi River opposite Warkworth, and lime was then made from boulders of limestone found in the stream-bed. Cox* in 1882 mentions Palmer's old lime-kiln below Mahurangi Falls, and this is perhaps the kiln erected in 1865. In 1870 Mr. Nathaniel Wilson began the manufacture of agricultural lime from the argillaceous limestone east of Warkworth, but the product was soon found to be a superior hydraulic cement, and the present extensive works of Wilson's Portland Cement Company have gradually come into existence owing to that fact.

Mr. Neill states that the cement rock or argillaceous limestone near Warkworth forms two distinct areas separated by the Mahurangi River and by hills of overlying green sandstone. In the great quarry close to the cement-works the argillaceous limestone is seen to resemble that of Limestone Island very closely. It is, however, somewhat softer, and is almost free from calcite stringers and veins. In quality it is very uniform. The mass of the rock is much shattered and slickensided. The total area underlain by argillaceous limestone near Warkworth is several hundred acres, and since the rock is of great though undetermined thickness it follows that many millions of tons are available.

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* Rep. of Geol. Explor. during 1881, No. 14, 1882, p. 21.

The Wilson's Portland Cement Company, besides making cement and "hydraulic lime," make agricultural lime by "burning" shells obtained from large shell-beds at Wairoa South. The calcination is done in circular concrete brick-lined kilns, with gas-coke as the fuel. Alternate layers of fuel and shells are charged into the kilns, and the action is continuous, fuel and shells being added on top as lime is withdrawn from the bottom. The lime is slaked with water so as to form an almost pure hydrated lime.

The following analyses of the Warkworth or Mahurangi limestone rock may be given :- -

	(1)	(2)	(3)	(4)	(5)	(5)	(7)	(8)	(9)
Matter insoluble in acid ..	14·75	10·4	21·16	23·96	18·91	29·50	23·55	16·82	51·6
Silica soluble in acid ..	Traces	13·2	..	..	..	..	..	3·07	..
Alumina and oxides of iron ..	0·81	6·8	4·58	1·24	4·26	2·40	0·50	2·20	..
Calcium carbonate ..	82·20	64·5	68·78	67·16	68·93	60·32	70·85	74·37	44·1
Magnesium carbonate ..	2·24	5·1	2·29	2·03	1·70	..	..	2·44	..
Magnesia	..	..	..	..	..	0·75	0·97	..	..
Water, loss, &c.	..	..	3·19	5·61	6·20	1·13	2·43	1·10	4·3
	100·00	100·0	100·00	100·00	100·00	94·10	98·30	100·00	100·0

References.—(1) Subcrystalline limestone from Mahurangi. Col. Mus. and Lab. 7th Ann. Rep., 1872, pp. 18–19. Lab. No. 1203. The analyst (W. Skey) states, "The sample was sent as a dressed block, and is a hard compact non-absorbent stone, almost a marble. It is reported to be procurable in large blocks, and near a good shipping-place. Its composition shows that it would make a fair stone for burning into quicklime."

(2) Light-yellow-coloured moderately hard but porous limestone from Mahurangi, forwarded by Mr. J. E. Evans. Col. Mus. and Lab. 13th Ann. Rep., 1878, p. 23. Lab. No. 2053.

(3) Siliceous limestone from Mahurangi, forwarded by Mr. Decimus Atkinson. Col. Mus. and Lab. 17th Ann. Rep., 1882, pp. 30–31. Lab. No. 3087.

(4) Limestone as quarried, and (5) ground limestone from Mahurangi, forwarded by the Public Works Department. Col. Mus. and Lab. 25th Ann. Rep., 1891, p. 58. Lab. Nos. 5357/1, 2.

(6) (7) Analyses of Warkworth cement rock, by Mr. J. A. Pond. Quoted by Mr. J. C. Neill.

(8) (9) "Silicified limestone and clayey marl" from Warkworth. Col. Mus. and Lab. 17th Ann. Rep., 1882, p. 31. Lab. Nos. 3110/1, 2. It is not clear why No. 8 is called a "silicified limestone" by Skey. It resembles the ordinary argillaceous or hydraulic limestone of North Auckland in composition. Skey remarks, "The limestone is more adapted for building purposes than for the manufacture of lime. The marl is a valuable manurial agent."

About 8 chains from Mr. J. G. Parry's wharf at Pukapuka, some miles south of Warkworth, much-shattered argillaceous limestone outcrops for 3½ chains in a road-cutting. From 3 ft. to 6 ft. of stone is visible. A sample collected by Mr. M. Ongley in February, 1917, was found to contain 77 per cent. of calcium carbonate. Lab. No. H 322/13.

Kawau Island.

The geological map of Kawau Island made by Hector (see 1869 report) shows that a series of Tertiary rocks, consisting principally of sandstones and grits, occupies considerable portions of the island. The largest patch occupies the north-east part of the island, and overlies much older rocks with an unconformity beautifully shown in the sea-cliffs (P. G. Morgan, MS.). In the south part of the island are three patches of the Tertiary rocks, which in order of size are—one north of the old copper-mine, one extending west from Limestone Point, and one east of Fossil Point. In the two last-named localities the principal rocks are calcareous grits and sandstone, which in places pass into conglomeratic limestone. At Limestone Point there are low broken cliffs of the calcareous grit, with bands of almost pure limestone. Analysis No. 1 below represents a block consisting "of water-worn fragments of clay slate (argillite) cemented by tolerably pure carbonate of lime, having a subcrystalline structure." Cox (in 1882) states that the conglomerates or pebble beds between the old copper-mine and Momona in their higher beds become calcareous, and pass into a sort of impure limestone, above which is a marl. Marly beds and concretionary sandstone occur on the north-east side of the island.

In places the old slaty rocks of Kawau Island are calcareous, and are traversed by thin veins of calcite.

The following analyses of calcareous rocks are ascribed to Kawau Island, but Nos. 2 and 3 are probably from the mainland (see below):—

	(1)	(2)	(3)
Calcium carbonate	64·9	65·92	66·61
Magnesium carbonate	1·5	..	..
Alumina and oxides of iron	1·9	..	..
Matter insoluble in acid	31·7	..	..
	100·0	..	..
Hygroscopic water (per cent.)	1·8	..	..

References.—(1) Rep. of Geol. Explor. during 1868–69, No. 5, 1869, p. 47.

(2) (3) "Calcareous mudstones from the Island of Kawau, collected by Mr. McKay." Col. Mus. and Lab. 19th Ann. Rep., p. 26. Lab. Nos. 3674/1, 2. These samples are almost certainly not from Kawau. On p. 46 of the report quoted they are listed as from Kawakawa. On p. 58 of the 25th Ann. Rep. (1891) they are ascribed to Mahurangi. There is no evidence extant that Mr. McKay ever visited Kawau.

Summary of Limestone Resources and of Means of Transport.

Rodney County has abundant supplies of low-grade argillaceous limestone suitable, after being pulverized, for use as a soil-dressing, but is not known to have any large deposit of high-grade stone. With the open sea and several harbours on its east coast, and with Kaipara Harbour as its western boundary, the county has good sea communications. It is traversed by the North Auckland Railway, but, as in most other parts of North Auckland, the roads are not good. Though in many places stone suitable for roadmaking is not close at hand, yet the county as a whole is better provided with rocks suitable for macadamizing than might be supposed, and the sea and railway communications allow roadmaking material to be obtained from outside areas. It may here be pointed out that the proper roading of North Auckland, the so-called "roadless North," depends on the completion of the North Auckland Railway, together with the making of a detailed investigation of the roadmaking materials and of the means of transport from localities with good stone to those less fortunate in that respect. The compilation of data of this kind will enable road engineers to prepare comprehensive schemes for highway communications. North Auckland is not the only part of New Zealand where the investigation of materials suitable for road-construction ought to be systematically undertaken.

Literature.

The chief references to the geology of Rodney County and Kawau Island are the following:—

Rep. of Geol. Explor. No. 5, 1869, pp. 45–48, and map (Kawau Island); No. 13, 1881, parts of pp. xiii–xv, and 13–39; No. 14, 1882, parts of pp. 17–32 (Kawau Island, pp. 28–32); No. 16, 1884, pp. 104–6; No. 19, 1888, parts of pp. 37–57; No. 21, 1892, p. 161.

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914 (2nd ed., 1915), pp. 157–58 (Warkworth district). 9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, pp. 87, 88, 89 (Kaipara Flats, Warkworth, &c.). 10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, part of pp. 11–13.

9. Waitemata County.

Waitemata County may be roughly divided into three parts. The first is the peninsula west of the southern part of Waitemata Harbour.* The rocks of this peninsula seem to be mainly blown sand and red incoherent cross-bedded sandstones, also of aerial origin. Hence south to Manukau Harbour is the hilly country containing the Waitakerei Range, and formed almost wholly of volcanic rocks of Middle Tertiary and later age. The rest of the county is of milder relief, and is formed very largely of the claystones, sandstones, and other rocks that collectively are termed the Waitemata Series or beds. The alluvial flats of the Kaipara River near Helensville and at the head of Auckland Harbour need no more than passing mention. There is much volcanic material in the rocks of the Waitemata Series, and in many places it predominates over the other constituents. Volcanic tuffs and breccias, distinctly younger than the Waitemata Series, also occur. Near Devonport are several volcanic cones of Pleistocene or even Recent age. Mount Rangitoto, close by, may have been in eruption within the last few thousand years. In the Wade or Silverdale district there are probable Cretaceous rocks, consisting of chalky or argillaceous limestone, marly clays, and concretionary sandstones and shales. These rocks extend west and north-west through Dairy Flat towards Helensville, and may also occur southward towards Redvale and Albany It may be noted, however, that in 1881 Cox mapped all this area as of Lower Miocene age.

Waitemata County is deficient in high-grade limestones, but there are many places where calcareous rocks containing from 60 to 85 per cent. of calcium carbonate occur. These are generally soft, and, though not suitable for burning into lime, may be readily crushed and applied direct to the soil. To some extent the lack of first-class limestone is counterbalanced by shell deposits in Auckland Harbour and elsewhere.

The rocks of the Waitemata Series are more or less calcareous, and in places an impure limestone may even appear; but the limestone beds of Kaukapakapa, Silverdale, Redvale, and Albany probably belong to an older series, and in some cases at least, as at Silverdale or Wade, are presumably of Cretaceous age. The confusion that exists in the literature dealing with the geology of North Auckland will, as previously stated, no doubt be removed by systematic geological survey, but would probably never have arisen if the hydraulic limestones and associated rocks were even moderately fossiliferous in a few of the localities where they have been examined.

Limestone in unknown amount exists near Kaukapakapa, north-east of Helensville. A sample forwarded from there by Mr. F. Dye in 1910 contained 73·75 per cent. of calcium carbonate. (Dom. Lab. 44th Ann. Rep., 1911, p. 15; Lab. No. A 1074.) The analysis of another sample forwarded by the same gentleman in 1916 is given as No. 2 of the table below:—

	(1)	(2)
Silica, or matter insoluble in acid	38·24	14·46
Alumina and oxides of iron	7·56	4·08
Lime	26·12†	42·36
Magnesia	Trace	0·92
Carbonic anhydride	20·53†	33·28
Moisture and organic matter	6·95	4·02
	99·40	99·12
Calcium carbonate (per cent.)	46·65	75·64

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* Usually called Auckland Harbour, as is done elsewhere in this bulletin.

† Recalculated from calcium carbonate, 46·65 per cent.

References.—(1) Aston, B. C., in the *Journal of Agriculture*, vol. 11, No. 3, Sept., 1915, p. 237. Analyst's number, L 701. Date, 1910. (See also Dom. Lab. 43rd Ann. Rep., 1910, p. 52.)

(2) Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 1397.

Several other analyses have lately been published by B. C. Aston (Jour. Agric., vol. 17, No. 2, Aug., 1918, p. 99).

In the Silverdale or Wade district numerous outcrops of somewhat poor limestone occur. In the early part of 1917 Mr. M. Ongley, Assistant Geologist, visited outcrops on the farms of Messrs. Bridson, west of Silverdale, and of Messrs. Mappin, Birks, and Carter, to the east of Silverdale, and south of Weiti River.

On Mr. Bridson's property, Sections 12, Block X, and 14, Block XI, Waiwera Survey District, argillaceous limestone of somewhat coarse grain outcrops in slips on the hillsides and in a creek. Mr. Bridson states that the rock is about 3 ft. under the surface of the greater part of his farm, and that it has been penetrated by a bore to a depth of 300 ft. The hill with the principal outcrops rises to a height of 110 ft. above sea-level, and the locality is suitable for quarrying. Boring or other form of prospecting is advisable in order to ascertain the amount and quality of the stone. A sample of limestone taken here was found to contain 56·5 per cent. of calcium carbonate (Lab. No. H 322/27).

On Mr. Mappin's farm, Section 81, Block XI, Waiwera Survey District, shattered argillaceous limestone, fine-grained and light-coloured, is exposed for 20 ft. at tide-level on the bank of Fisherman Creek. The stone is slickensided and broken into small flakes, most of which are recemented by calcite. At low water it is seen to extend more than half-way across the stream. A bore drilled for water near Mr. Mappin's house penetrated 15 ft. into limestone. There are several small outcrops of shattered limestone higher up Fisherman Creek, and others are stated to occur in the neighbourhood. A sample of limestone from Fisherman Creek contained 78·5 per cent. of calcium carbonate (Lab. No. H 322/26).

On Mr. Birks's property, part of Section 2, Block XI, Waiwera Survey District, east of Mr. Mappin's, 4 ft. of shattered and slickensided limestone outcrops 30 ft. above a small stream and 15 chains from tide-water. At the stream-level is another outcrop of similar stone resting on shattered mudstone. The limestone readily crumbles on exposure to the weather, and has been used by Mr. Birks as a soil-dressing with good results. It is coarser in grain and somewhat lighter-coloured than that on Mr. Mappin's land. A sample yielded 41 per cent. of calcium carbonate (Lab. No. H 322/2).

On Mr. Carter's land, part of Section 2, Block XI, Waiwera Survey District, and east of Mr. Birks's, small outcrops of shattered argillaceous limestone appear at tide-level on Duck Creek. A sample yielded 43 per cent. of calcium carbonate (Lab. No. H 322/4). It is thought that the limestone extends under all or the greater part of this and the neighbouring properties. In order to prove this a considerable amount of prospecting by means of trenching and boring will be necessary.

On the banks of the Weiti Stream, near the branch road that gives access to Mr. A. G. Sainsbury's farm, argillaceous limestone outcrops for some distance, forming cliffs 10 ft. to 20 ft. high. The rock is dirty-grey in colour and of somewhat harsh grain. It is friable, and in places much veined by calcite. Eight samples were taken by Mr. Sainsbury, and five of these were analysed with the following results: No. 1, 75·95 per cent. of calcium carbonate; No. 2, 75·55 per cent.; No. 3, 65·45 per cent.; No. 5, 58·38 per cent.; No. 8, 75·24 per cent. (Dom. Lab. No. H 2343/1–5.) Mr. Sainsbury's No. 4 specimen consisted of calcite veins, and was therefore almost pure carbonate of lime. His samples Nos. 6 and 7 were similar to those analysed. The numbering of the samples begins from the point nearest the end of the road mentioned above.

A previous sample, sent in July, 1917, from some part of Mr. Sainsbury's farm, was analysed with the following results:—

	Per Cent.
Matter insoluble in acid	19·42
Calcium carbonate	71·50
Phosphoric anhydride	0·11

Another limestone area visited by Mr. Ongley is south of Wade, on land rising 300 ft. or more above sea-level. At several places on Section 29, Blocks XI and XV, Waiwera Survey District (owned by Mr. Matthews), shattered argillaceous limestone outcrops, or can be exposed by trenching the ground. On the road through this section, at 270 ft. above sea-level, shattered limestone is seen outcropping in the water-table for 50 yards. It could be easily quarried at this place. A sample taken here contained 63·5 per cent. of calcium carbonate (Lab. No. H 322/5). Some distance west of the road, at a point 120 ft. above sea-level, is an outcrop of more solid limestone. This appears to dip westward at an angle of 60°, but the bedding-planes are uncertain. A sample taken here yielded 75·5 per cent. of calcium carbonate (Lab. No. H 322/6).

In addition to the analyses quoted above, which have the advantage of exactly specifying the locality in which the samples analysed were obtained, the following analyses of limestone from Silverdale and its neighbourhood may be given:—

	(1)	(2)	(3)
Matter insoluble in acid	20·21	21·31	..
Alumina and oxides of iron	2·64	3·17	..
Calcium carbonate	70·19	74·05	86·55
Magnesium carbonate	1·98	1·47	..
Water and organic matter	4·98	..	..
Phosphoric anhydride	..	..	0·32
	100·00	100·00	..

References.—(1) Argillaceous limestone from Wade, collected by Mr. Alexander McKay. Col. Mus. and Lab. 20th Ann. Rep., 1886, p. 40. Lab. No. 3845.

(2) From Silverdale, forwarded by Mr. G. H. Carter in 1913. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 1204. The " magnesium carbonate " includes " undetermined."

(3) From Silverdale, forwarded by J. R. Curley, per Mines Department. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 529.

At Redvale, in the valley of the Okura Stream, a few miles south of Silverdale, shattered, slickensided, argillaceous limestone similar to that farther north outcrops in several places. On Mr. Chapple's land, Section 53, Block XV, Waiwera Survey District, a quarry has been opened at a point about 10 ft. above sea-level and half a mile from tide-water. The face shows 15 ft. of limestone, covered by 3 ft. of soil. The limestone as broken in the quarry is sold for 3s. per ton, and used as a soil-dressing. It is found that the lumps, owing to their friability, readily disintegrate in the soil. The results of experimental work at Albany with this limestone are stated in the *Journal of Agriculture* for January, 1916, pages 10–12. Mr. Chapple states that he has traced the limestone for half a mile on his property, and that it also occupies a considerable area of neighbouring land. A sample taken by Mr. Ongley from the quarry contained 80 per cent. of calcium carbonate (Lab. No. H 322/3).

On Section 60, east-south-east of Chapple's, owned by Redgate Bros., a shaft was sunk many years ago in limestone under the impression that it was gold-bearing quartz. Ten chains upstream from the public wharf 4 ft. of crushed limestone shows on the stream-bank at tide-level. Some lumps of greyish coarse crystalline limestone are also lying about. The Messrs. Redgate state that the limestone is traceable for several chains, and think it is continuous with that on Mr. Chapple's land. A sample of the crystalline limestone found loose on their property was found to contain 92 per cent. of calcium carbonate (Lab. No. H 322/7).

Somewhat numerous analyses of limestone from Redvale or its neighbourhood have been made during the past few years. Those available at the time of writing are given in the following tabulation:—

	(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)
Matter insoluble in acid ..	16·48	21·33	29·64	16·54	47·35	19·14	14·46	..
Alumina and oxides of iron..	2·26	3·10	3·16	1·94	8·33	1·58	1·20	..
Calcium carbonate ..	79·28	73·82	65·98	81·01	42·46	78·33	82·77	44·70
Magnesium carbonate and undetermined	1·98	1·75	1·22	0·51	1·86	0·95	1·57	..
Phosphoric anhydride ..	..	..	..	..	..	..	..	0·16
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	..
Quicklime in calcined stone, per cent. (Aston) ..	68	61	52	70	30	67	73	..

References.—(1) (2) (3) (4) From Redvale, forwarded by Director, Fields Division, in 1913. Dom. Lab. 47th Ann Rep., 1914, p. 22. Lab. Nos. D 947/1, 2, 3, 4. The additional cryptic information that No. 3 is from the same locality as No. 1 is given.

(5) From Redvale, forwarded by Mr. Foley in 1913. Same reference as above. Lab. No. D 970.

(6) (7) From Okura, forwarded by S. R. Smith in 1914. Dom. Lab. 48th Ann. Rep, 1915, p. 20. Lab. No. E 245/1, 2.

(8) From Redvale. Forwarded by Secretary for Agriculture in 1911. Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 162.

By consulting the literature cited below references to calcareous rocks in other parts of Waitemata County may be found—for example, the polyzoan breccia on the coast some distance north of Lake Takapuna. On Motutapu Island, east of Rangitoto, is a gritty shell-bed, 3 ft. thick, which contains many fossils, especially the gigantic cirripede *Pollicipes aucklandicus* (Hector) Benham,* which was later renamed *Hexelasma aucklandicum* Hector sp. by Withers.† A similar bed is perhaps to be found on the east side of Rangitoto Island. A freestone with 78·86 per cent. of calcium carbonate has been reported from Big Muddy Creek, a stream entering Manukau Harbour north-east of Puponga Point. On the shores of the county and in Auckland Harbour are various shell deposits, some of which have yielded considerable amounts of material used for making lime and cement. The following miscellaneous analyses may here be introduced:—

	(1)	(2)	(3)	(4)
Matter insoluble in acid ..	15·77	14·10	10·07	33·20
Silica dissolved by acid ..	1·16	..	..	..
Alumina and iron oxides ..	1·80	1·86	2·12	5·22
Calcium carbonate	78·86	83·91	83·27	51·33
Magnesium carbonate and undetermined (in Nos. 2 and 3)	2·41	0·13	4·54	1·87
Water, &c.	..	..	..	7·25
	100·00	100·00	100·00	98·87
Quicklime in calcined stone (per cent.)	..	74	..	..

References.—(1) Freestone from Big Muddy Creek, forwarded by J. J. Symonds. Col. Mus. and Lab. 9th Ann. Rep., 1874, pp. 18, 32. Lab. No. 1595. The analyst remarks that this "is a fine-grained coherent homogeneous stone, only feebly absorbent of water, and is a valuable stone for building purposes."

(2) From Waitemata County, forwarded by Sandford and Earwaker. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. No. E 393.

(3) Ground oyster-shells, Auckland, forwarded by G. Rhodes and Sons. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. No. E 677.

(4) From "Auckland." Dom. Lab. 43rd Ann. Rep., 1910, p. 52. Lab. No. L 191.

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* Benham, W. B.: "Remains of a Gigantic Fossil Cirripede from the Tertiary Rocks of New Zealand." *Geological Magazine*, n.s., dec. iv, vol. 10, pp. 110–19, March, 1903.

† Withers, T. H.: "Some Miocene Cirripedes of the Genera *Hexelasma* and *Scalpellum* from New Zealand." Proc. Zool. Soc. Lond., 1913, pt. iii, pp. 840–54.

In the 12th Annual Report of the Department of Agriculture, Chemical Division, 1904, page 143, eight more analyses of limestones from "Auckland" are given. These contain from 64·62 to 90·02 per cent. of calcium carbonate, and are numbered E 311, 312, 313, 314, 316, 317, 318, and 114. Other analyses of limestones from Waitemata County and from "Auckland" have lately been published by Aston (Jour. Agri., as previously cited, pp. 99, 100).

Hector and Skey, in "Reports and Awards of the Jurors, N.Z. Exhibition, 1865" (Dunedin, 1866), mention (pp. 401, 451) two calcareous sandstones or freestones—one from "Motupipi, Auckland," and one from "Auckland"—which contain 30·27 and 37·60 per cent. respectively of calcium carbonate. (See also appendix to Chapter III of this bulletin.)

Summary of Limestone Resources and of Means of Transport.

In the Wade (Silverdale) and Okura (Redvale) districts, and perhaps also thence towards Kaukapakapa, there appear to be large amounts of a rather poor argillaceous limestone, which is unfit for making quicklime, but after being coarsely pulverized is suitable for spreading on the land. The rock is easily quarried, but in some places difficulty in working it may be caused by its being below the drainage-level of the surrounding country. A considerable amount of exploration and prospecting is necessary in order to obtain exact information as to the distribution of the limestone.

The shelly beaches and banks on or near the coast-line may probably be relied upon to furnish considerable amounts of carbonate of lime suitable for the manufacture of quick and slaked lime.

Means of communication and transport in Waitemata County are good. It has several harbours on its sheltered east coast, Auckland and Manukau harbours on the south, and Kaipara Harbour in the north-west. The county is traversed by the North Auckland Railway. The roads in many parts, however, are not very good.

Literature.

The chief references to the geology of Waitemata County are,—

Hochstetter, F. von: "New Zealand" (English translation, 1867). Chapters xi, xii, and part of xiii deal largely with the area now included in Waitemata County.

Rep. of Geol. Explor., No. 13, 1881, parts of pp. 13–39 and geological map opposite p. 28; No. 16, 1884, pp. 99–101, 101–6; No. 17, 1886, parts of pp. xxxvii–xl and 147–64; No. 18, 1887, part of pp. 219–29; No. 19, 1888, pp. 39–40, 54–55; No. 21, 1892, p. 174 (Summary of Geology).

Park, James: "On the Conformable Relations of the different Members of the Waitemata Series." Trans. N.Z. Inst., vol. 22, 1890, pp. 391–99.

Shrewsbury, Hugh: "The Auckland Volcanoes." Trans. N.Z. Inst., vol. 24, 1892, pp. 366–80.

Park, James: "On the Prospects of finding Workable Coal on the Shores of the Waitemata." Trans. N.Z. Inst., vol. 24, 1892, pp. 380–84.

Mulgan, E. K.: "On the Volcanic Grits and Ash-beds in the Waitemata Series." Trans. N.Z. Inst., vol. 34, 1902, pp. 414–35.

Fox, C. E.: "The Volcanic Beds of the Waitemata Series." Trans. N.Z. Inst., vol. 34, 1902, pp. 452–93.

Clarke, E. de C.: "The Fossils of the Waitemata and Papakura Series." Trans. N.Z. Inst., vol. 37, 1905, pp. 413–21.

Other papers and reports dealing with the Waitemata Series will be cited under Manukau County.

10. Eden County.

Eden is a small county extending from the narrow neck or peninsula known as the Whau to Tamaki Inlet. Geographically it includes Auckland City, though politically this, as well as the outlying boroughs of Newmarket, Mount Eden, Mount Albert, and Onehunga, are of course distinct.

The chief geological formations are the sedimentary rocks of the Waitemata Series or beds, and the lavas and tuffs deposited by Pleistocene and possibly even Recent volcanoes. Apart from the calcareous layers and concretions of the Waitemata Series there are no carbonate-of-lime deposits in the county, and for lime it must rely on outside sources, or the shell beaches and banks of Auckland Harbour, &c. At Orakei on the eastern side of Hobson's Bay, and also on the western side of the bay, there are irregular foraminiferal beds which in places may be moderately calcareous. These beds, being more fossiliferous than other portions of the Waitemata Series, occupy a prominent place in the literature. Much controversy has taken place concerning the age, stratigraphy, and subdivision of the Waitemata Series, and the nature of its relations to the underlying rocks.

For the sake of completeness the presence of calcareous concretions in the Recent muds of Auckland Harbour may be mentioned.

Analyses 3 and 4 on the lower part of page 69, under the heading of "Waitemata County," are ascribed to Auckland samples, and ought perhaps to be quoted here; but the matter is one of little moment.

Containing, as it does, the large city of Auckland and most of its suburbs, Eden County is well provided with means of transport.

Literature.

Most of the literature cited above under Waitemata County, and that on a later page under Manukau County, has a bearing on Eden County.

The calcareous concretions of Auckland Harbour are described by J. A. Bartrum in a paper entitled "Concretions in the Recent Sediments of the Auckland Harbour, New Zealand," appearing in the "Transactions of the New Zealand Institute," vol. 49, 1917, pp. 425–28. Another paper that may most conveniently be cited here is that by F. W. Hutton, "On the Age of the Orakei Bay Beds, near Auckland," in the Trans. N.Z. Inst., vol. 17, 1885, pp. 307–13. (See also Rep. of Geol. Explor., No. 14, 1882, pp. 27, 28, 94–96; and No. 21, 1892, p. 152.)

11. Manukau County.

The eastern part of Manukau County is mainly formed of Early Mesozoic greywackes and argillites. The outlying islands (Waiheke, Ponui, Pakihi, &c.) are composed wholly or mainly of similar rocks. West of these rocks are possible coal-bearing strata, consisting of conglomerates, sandstones, clays, and limestones, but no coal is known to occur in the county as at present defined. In the northern part of Manukau the Waitemata Series is fairly well developed, especially along the coast-line westward from Maraetai. In Tamaki River watershed southward and westward the Waitemata and any older rocks are hidden by volcanic rocks (both flows and fragmental material) and by a series of geologically young clays and sands. Apart from the calcareous bands of the Waitemata beds, the only limestone that can be expected to occur in Manukau County must be looked for in the belt of country south of the large bay into which Waikopua and Turanga creeks discharge. This belt, passing east of Papakura, extends into Franklin County. In it is developed, but somewhat poorly, a Tertiary limestone known as the Papakura limestone. This corresponds in age with the Waikato and perhaps also with the Raglan and Kawhia limestones, &c., but whether it is to be correlated with the Whangarei limestone is another matter that will be keenly disputed.* What is no doubt the Papakura limestone is exposed in both branches of the Waikopua Creek, a stream that drains part of the Maraetai Hills. Park describes the occurrence as follows: "About two miles from its mouth the Waikohu (Waikopua) divides, and in both branches, a short distance above the junction, occurs a coarse slate-breccia cemented by lime, and lying on the denuded edges of the slates. This breccia passes into a limestone, which is more or less impure throughout." (Rep. Geol. Explor. during 1885, No. 17, 1886, p. 152.) The Papakura limestone is seen again in Hay or Slippery Creek, eastward of Papakura, but at a point in Franklin County. Here also it is impure. Apparently it has not been traced through the intervening country. The two analyses given below probably represent limestone from the Waikopua Creek watershed:—

	(1)	(2)
Matter insoluble in acid	28·31	39·67
Alumina and iron oxides	2·38	4·94
Calcium carbonate	69·13	53·56
Magnesium carbonate and undetermined	0·18	1·83
	100·00	100·00

Reference.—Limestone from Whitford, forwarded by C. Ray. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. Nos. E 637/1, 2.

In the *Journal of Agriculture*, vol. 17, No. 2, Aug., 1918, p. 99, B. C. Aston mentions a sample of stone from Clevedon with 42·1 per cent. of carbonate of lime. On page 100 six analyses of limestone from the same locality are tabulated. The percentages of calcium carbonate given are: 83·7, 81·2, 78·6, 87·3, 85·7, and 98·2.

Summary of Limestone Resources and of Means of Transport.

It will be seen that Manukau County has poor limestone resources. It is, however, traversed by a railway, and has an extensive coast-line, so that the problem of transporting lime to most parts of the county is not serious. Along the coast are shell-beds, and some of these may be extensive. Shells from the southern Wairoa, as mentioned on page 64, have been shipped to the Wilson's Portland Cement Company's works near Warkworth for the purpose of making lime.

Literature.

Most of the publications cited under Waitemata County, especially those in the "Transactions of the New Zealand Institute," refer also to Manukau County. The following are the chief references in the old Geological Survey reports:—

Rep. of Geol. Explor., No. 14, 1882, part of pp. 33–36, and map at end; No. 17, 1886, parts of pp. xxxvii–xl and 147–64; No. 19, 1888, parts of pp. xxxiv–xxxv, 16–18, and 40–42; No. 21, 1892, p. 157.

In addition the following papers should be consulted:—

Hutton, F. W.: "On the Relative Ages of the Waitemata Series and the Brown Coal Series of Drury and Waikato." Trans. N.Z. Inst., vol. 3, 1871, pp. 244–49.

Clarke, E. de C., in Marshall, Speight, and Cotton: "The Younger Rock Series of New Zealand." Trans. N.Z. Inst., vol. 43, 1911, pp. 378–407. Clarke's contribution is on pp. 396–99.

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* Recent surveys by Dr. J. Henderson in south-west Auckland and north Taranaki indicate that two imestones, of which the Kawhia is the older, are present in that region. This throws doubt on the statements made in the text, and tends to confirm Hutton's early work (see Trans. N.Z. Inst., vol. 3, 1871, and Rep. of Geol. Explor., No. 2, 1867).

12. Franklin County.

Franklin County extends from the west coast of the North Island, south of Manukau Heads and north of the Waikato River, to the Firth of Thames. North and south it may be defined as extending from Papakura to a little beyond Mercer, both well-known stations on the Auckland–Wellington or Main Trunk line. Its geology is very similar to that of Manukau County, except that undoubted Waitemata beds are not visible. In the west and to some extent in the middle of the county is volcanic material, in the east a Mesozoic rock-series. Coal-measures are better developed than in Manukau, and in past years have been worked at Drury. A calcareous claystone called by Cox the "Leda" marl, which resembles some of the Waitemata beds, but is probably older, outcrops near Mercer.

The only limestone deposit known in Franklin County is that previously mentioned as occurring in Hay or Slippery Creek, south-east of Papakura. Geologists who have seen this rock state that it is decidedly impure. B. C. Aston, however, in the publication cited above (Aug., 1918) lists two samples of limestone from Papakura, one with 88·1 and the other with 88·2 per cent. of calcium carbonate. The county of origin is given in error as Manukau. In addition the coast-line of the county may yield small supplies of shelly material, but it is clear that much of the lime required by agriculturists will have to be obtained from outside sources.

Means of Transport.

Franklin County has fairly good transport facilities. The central part is traversed by the Main Trunk Railway. Arms of Manukau Harbour penetrate deeply into the western part of the county, which also has the navigable Waikato River as its southern boundary. A railway-line from Paerata to Waiuku is under construction, and probably will shortly be completed. The extreme east of the county has a sheltered coast-line, where lime could easily be landed from small vessels.

Literature.

The chief references to the geology of Franklin County will be found in the following publications:—

- Hochstetter, F. von.: "New Zealand" (English translation, 1867). See pp. 78–81, 258–81, 289–94, &c.
- Rep. of Geol. Explor., No. 7, 1872, p. 117; No. 10, 1877, pp. 12, 114–21; No. 14, 1882, pp. 33–36; No. 17, 1886, pp. 153–54; No. 19, 1888, pp. xxxiv–xxxv, 16–18, 41–42; No. 20, 1890, pp. lv–lvi.
- 8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914 (2nd ed., 1915), p. 156.

The paper by Hutton in vol. 3 of Trans. N.Z. Inst. (pp. 244–49) and those by Clarke in vols. 37 (pp. 413–21) and 43 (pp. 396–99), previously cited under the headings of Waitemata and Manukau counties, should also be consulted.

13. Barrier County, Little Barrier Island, etc.

Great Barrier or Aotea Island is now constituted as a county, and therefore obtains a separate heading. The island has a basement of Mesozoic sedimentary rocks (greywackes and argillites) in great part covered by Tertiary volcanics. With the exception of some calcite veins penetrating the volcanic rocks, and of shell deposits on the coast, the island has no known deposits of carbonate of lime. Little Barrier or Hauturu Island is represented on Hector's geological maps of 1869 and 1873 as composed of volcanic rocks, but in the geological map of 1883 (published in Reports of Geological Explorations during 1883–84, No. 16, 1884) it is shown as composed of Palæozoic rocks—that is, of rocks similar to the old sedimentaries of Great Barrier Island, which are here regarded as of Mesozoic (Trias-Jura) age. The topography of the Little Barrier Island as seen from a distance indicates the correctness of the later view.

Literature.

The following references to the geology of Great Barrier Island may be cited :—

Hutton, F. W.: "Report on the Geology of the Great Barrier Island" (with map). Rep. of Geol. Explor. during 1868–69, No. 5, 1869, pp. 1–7. Calcite veins, p. 3.

Trans. N.Z. Inst., vol. 1, 2nd. ed., 1875 (1st ed., 1869). In this, pp. 88–101, 104–106, and 108–12, are various papers by F. W. Hutton and T. W. Kirk on the botany and zoology of Great Barrier, Little Barrier, and Arid islands. Some geological notes will also be found. Trans. N.Z. Inst., vol. 19, 1887, pp. 193–94 (moa-remains); vol. 22, 1890, pp. 79–84.

Park, James: "The Geology and Veins of the Hauraki Goldfields." Trans. (also Minutes of Proceedings) N.Z. Inst. Min. Eng., vol. 1, 1897. Pages 102–5 deal with Great Barrier Island.

McKay, Alex.: "Report on the Silver-bearing Lodes of the Neighbourhood of Blind Bay, Great Barrier Island." Parl. Paper C.–9, 1897, pp. 75–80 (bound with Mines Rep. for 1897).

14. COROMANDEL COUNTY.

The whole of Coromandel County has been geologically surveyed in detail by C. Fraser and J. H. Adams. It has a basement of Trias-Jura rocks* (fine conglomerates, greywackes, argillites, and interbedded igneous rocks) which in most parts of the county are smothered by Tertiary volcanic rocks. There are, however, various small patches of Tertiary sedimentary rocks (older than the volcanics) scattered over the northern half of the county. These rocks are assigned to the Torehine Series by Fraser and Adams, and consist of conglomerate, sandy shales with coal, marly sandstone, calcareous sandstone, limestone, &c. Near Torehine, a few miles north of Coromandel, the limestone as exposed on the coast-line is about 50 ft. thick, and dips at 15° to the east-north-east. It is a hard, compact, semi-crystalline, brownish-grey rock, composed largely of Polyzoa. Fraser and Adams† state, "There is no great area of this limestone exposed on the coast-line, and . . . it is doubtful how far it may extend inland. The fact that it is the only limestone exposed on the coast-line within the limits of the Hauraki Gulf renders it of economic importance as a flux for metallurgical purposes. This limestone affords small characteristic outcrops in the valley of Anthony Creek about half a mile from the coast-line."

In Branch Creek, a tributary of Umangawha Stream, near Cabbage Bay, limestone similar to that at Torehine occurs at an elevation of 700 ft. or more. The locality is almost due east of Torehine, and less than two miles from the sea as the crow flies, but a rugged ridge intervenes, and the shortest practicable outlet is down the valley of the Umangawha to Cabbage Bay, a distance of about four miles. Mr. D. V. Allen, formerly Director of the Coromandel School of Mines, states that "the limestone forms, at one point on the eastern side of the creek, a hill fully 100 ft. in height."† The beds of the

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* Some of the rocks may be of Palæozoic age.

† N.Z. Geol. Surv. Bull. No. 4, 1907, p. 56.

Torehine Series here strike 30° west of north, and dip to the east-north-east at angles approaching 35°.

Ninety-five chains east of Cape Colville several beds of shelly conglomerate from 1 ft. to 20 ft. thick, and interbedded with marly sandstone, mudstone, &c., are exposed on the coast-line. The strata strike north 60° west, and dip to the north-north-east at angles of 35° to 45°.

In the valley of Omoho Creek and that of its southern branch the Mangakotukutuku (near Kennedy's Bay) small patches of greenish-grey marly sandstones occur. The lowest outcrop in the main creek contains a 10 ft. band of very dark-coloured limestone, below which is a thin calcareous layer crowded with oyster-shells.

The available analyses of the Coromandel County limestones are given below :—

	(1)	(2)
Silica	10·2	3·5
Alumina and iron oxides	3·0	2·3
Lime	48·8	52·2
Magnesia	0·9	0·8
Carbon dioxide	36·9	40·5
Water and organic matter	..	0·7
Undetermined	0·2	..
	100·0	100·0
Calcium carbonate (per cent.)	81·6	90·0
Quicklime in calcined stone (per cent.)	77·3	88·8

References.—(1) Limestone from Torehine, collected by Geological Survey. N.Z. Geol. Surv. Bull. No. 4, 1907, p. 56, and Dom. Lab. 41st Ann. Rep., 1908, p. 18. Lab. No. 973.

(2) Limestone from Branch Creek, collected by Geological Survey. N.Z. Geol. Surv. Bull. No. 4, p. 56, and Dom. Lab. 41st Ann. Rep., p. 20. Lab. No. 1358. The calcined stone will contain approximately 91 per cent. of lime (B. C. Aston, 1915).

A sample of hard compact limestone from Amodeo Bay, Coromandel, forwarded in 1907 to the Dominion Laboratory by Mr. A. R. H. Swindley, through the Hon. the Minister of Mines, was found to contain 91·3 per cent. of calcium carbonate (Dom. Lab. 41st Ann. Rep., 1908, p. 18. Lab. No. 1074). This sample no doubt came from the Torehine outcrop, Amodeo Bay being just to the south.

In the *Journal of Agriculture,* vol. 17, No. 2, Aug., 1918, p. 99, B. C. Aston gives the following analyses: Torehine Point, 98·5 per cent. $CaCO_3$; Cabbage Bay, 81 per cent. $CaCO_3$.

Calcite and other carbonates occur in many of the gold-bearing quartz lodes of Coromandel County, and also occur as veins in the volcanic rocks. These occurrences as a rule are sufficiently described in the Geological Survey bulletins, and need no further mention here. Aragonite, which has the same chemical composition as calcite (see p. 16), also occurs (N.Z. Geol. Surv. Bull. No. 4, p. 102).

Summary of Limestone Resources and of Means of Transport.

Although the limestone areas are small, yet probably large amounts of good limestone could be mined at Torehine and at Anthony and Branch creeks. There would be no difficulty in shipping the stone at Torehine Point, and at Cabbage Bay there is a wharf, from which a road runs several miles up the Umangawha Valley. The county as a whole has magnificent sea communications, but poor roads. There are inexhaustible supplies of rock suitable for roadmaking; and the chief difficulty in roading the county, aside from the lack of money, is its hilly nature.

Literature.

The geological literature dealing with Coromandel County is extensive. For the purposes of this bulletin the following are the most important:—

McKay, Alex.: "Report on the Geology of the Cape Colville Peninsula, Auckland." Parl. Paper C.–9, 1897 (bound in Mines Rep.). Pages 47–49 deal with the limestone and associated rocks at Torehine and elsewhere.

Park, James: "The Geology and Veins of the Hauraki Goldfields, New Zealand." Trans. (also Min. Proc.) N.Z. Inst. Min. Eng., vol. 1, 1897, pp. 1–137. Considerable space is devoted to districts in Coromandel County.

Maclaren, J. M.: "Geology of the Coromandel Goldfields." Parl. Paper C.–9, 1900 (bound in Mines Rep.). Pages 6–7 deal with the limestone and associated rocks at Torehine, &c.

Fraser, Colin, and Adams, J. H.: "The Geology of the Coromandel Subdivision, Hauraki, Auckland." N.Z. Geol. Surv. Bull. No. 4 (N.S.), 1907. An exhaustive report on the geology of the northern two-thirds (measured by length) of Coromandel County. Special attention may be drawn to the detailed geological maps, which also show the topography.

Fraser, Colin: "The Geology of the Thames Subdivision, Hauraki, Auckland." N.Z Geol. Surv. Bull. No. 10 (N.S.), 1910. Deals with that part of Coromandel County which is in Hastings Survey District, and parts of Thames and Ohinemuri counties.

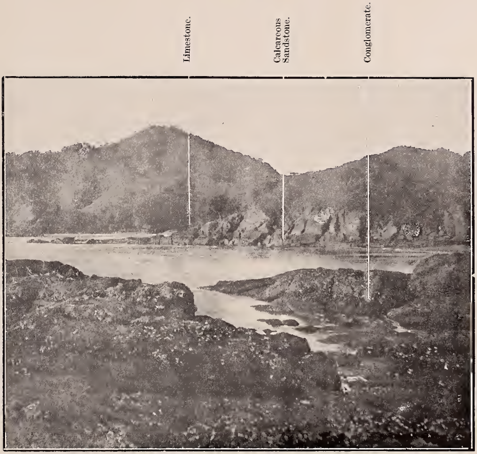
Bell, J. M., and Fraser, Colin: "The Geology of the Waihi-Tairua Subdivision." N.Z. Geol. Surv. Bull. No. 15 (N.S.), 1912. Deals with the geology of that part of Whitianga Survey District in Coromandel County (thus completing its geological survey), and the eastern part of Thames and Ohinemuri counties.

The remaining literature dealing with Coromandel County will be found listed, with few exceptions, in the three Geological Survey bulletins mentioned above. The full list is far too long to give here, but a few may be briefly indicated. The earliest literature consists of two papers by Charles Heaphy in vols. 10 and 11 of the *Quarterly Journal of the Geological Society*, 1854 and 1855. Hochstetter's "New Zealand" appeared in German in 1864, and in English translation in 1867 (for Coromandel see pp. 94–98). The chief references in the Reports of Geological Explorations (issued under the direction of Sir James Hector) are in No. 6, 1871, pp. 2–5 and 88–99; No. 14, 1882, pp. 40–41; No. 15, 1883, pp. xi–xv, 4–51; and No. 17, 1886, pp. 192–202 (Torehine limestone, &c., described by McKay). The following references to the "Transactions of the New Zealand Institute" may also be given: Vol. 2, 1870, pp. 367–68; vol. 26, 1894, pp. 360–64; vol. 31, 1899, pp. 490–98; vol. 32, 1900, pp. 213–15; and vol. 33, 1901, pp. 339–41. An important though in some respects disappointing publication is "Rocks of the Cape Colville Peninsula" (vol. 1, 1905; vol. 2, 1906), by Professor W. J. Sollas and Mr. Alexander McKay. This contains descriptions of many rocks from Coromandel County.

15. THAMES COUNTY.

The Mesozoic, or possibly in part Palæozoic, rocks that form the basement of Coromandel County extend into Thames, and are seen near Tapu and at Rocky Point, near the town of Thames. With the exception of a few small areas of Tertiary sedimentaries and the alluvial flats of the Piako, Waihou, Kaueranga, and other streams, the remaining parts of Thames County are covered by volcanic rocks, which in places contain richly auriferous quartz lodes. Near Thames, Waiomo, and probably elsewhere, these rocks contain a number of calcitic veins, some of which reach a foot

PLATE III.



A. LIMESTONE, ETC., TOREHINE, COROMANDEL COUNTY.

[*From Geol. Surv. Bull. No. 4.*]

B. LIMESTONE CLIFFS, NEAR WHANGAREI.

[*Photo by Tourist Department.*]

or two in thickness. Some of the quartz veins contain a good deal of calcite and other carbonates, such as dolomite.

C. Fraser, in N.Z. Geol. Surv. Bull. No. 10, p. 54, describes a calcite vein occurring in a small branch of Whalebone Creek, entering 22 chains below the junction of the Waipukapuka. Strange to say, the calcitic veins seen on the foreshore at various points between Rocky Point and the town of Thames are not mentioned. Park* in his paper of 1894 states that large veins and segregated masses of calcite are plentiful in the tuffs exposed on the beach near Waiohanga Creek.

An analysis of calcitic ore from the Day Dawn and Norfolk Mine, Tararu, will be found on page 72 of N.Z. Geol. Surv. Bull. No. 10. It indicates about 27 per cent. of calcium carbonate and 10 per cent. or more of other carbonates.

When decomposed the volcanic rocks of the Hauraki Goldfield invariably contain more or less carbonate of lime. It should be remembered that these rocks, if in a fresh unaltered state, contain several per cent. of lime, not as carbonate, but combined with other metallic oxides and with silica to form various complex silicates. It is noteworthy that the andesitic rocks in the south-east part of the goldfield contain much less lime than those in the Thames and Coromandel districts (N.Z. Geol. Surv. Bull. No. 15, 1912, p. 53). Calcite in the gold-bearing veins, however, is apparently much more abundant in the former district.

Summary of Limestone Resources and of Means of Transport.

The only known carbonate-of-lime resource of the county, apart from the calcite veins mentioned above, consists of the shell beaches and banks of the coast-line. The shell-banks off the mouth of the Piako River are reported to be large, and promise to be of great value in supplying the farms on the Piako or Hauraki Plain with much-needed lime.

The more settled portions of Thames County have good railway, road, sea, and river communications, so that there need be no great difficulty in introducing lime from other parts of the Auckland District.

Literature.

With the exception of a small area of plain west of the Piako River, the whole of Thames County has been geologically surveyed in detail. The results are embodied in N.Z. Geol. Surv. bulletins Nos. 10 and 15, the titles of which were quoted in full under Coromandel County. The voluminous literature dealing with the geology of the county is cited in those bulletins, and need not be relisted here.

16. OHINEMURI COUNTY.

The geology of Ohinemuri County is similar to that of Thames. The eastern part consists almost wholly of Tertiary rocks containing auriferous quartz lodes, which have been worked at Waihi, Waitekauri, Karangahake, and many other places. The middle and western parts are occupied almost wholly by the Hauraki Plain, but in the extreme west Mesozoic rocks (greywackes and argillites), together with some volcanic rocks of Tertiary age, appear.

The gold-bearing veins of Waitekauri, Waihi, and other places contain a great deal of calcite. As a rule this is not seen at the outcrops, but at some depth. At Golden Cross, Upper Waitekauri, an adit level driven on the west side of Waitekauri Creek passed through a lode that consisted largely of calcite. A crosscut at No. 1 level from

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* Park, James: "The Geology and Veins of the Hauraki Goldfields, New Zealand." Trans. N.Z. Inst. Min. Eng., vol. 1, 1897, p. 57 (also published as "Minutes of Proceedings").

No. 1 shaft passed through two such lodes. From No. 2 level downward to No. 5 level increasingly larger bodies of calcite were encountered in the main lode. Below No. 5 level the lode, so far as explored, was smaller, but calcite remained prominent. In the neighbouring Waitekauri Extended or St. Hippo Claim a calcite lode 20 ft. wide was encountered in the main crosscut.

At Waihi portions of the larger auriferous lodes consist largely, or in some cases almost wholly, of calcite, and there are small veins of almost pure carbonate of lime. It is possible that the mine dumps at Waihi could supply a few hundred tons of calcitic rock suitable for spreading on the cultivated land near the town.

The following analyses of calcitic lode material from various Ohinemuri mines may be inserted here:—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Silica (SiO_2)	0·73	39·95	4·22	0·48	0·65	12·10	17·40	28·46
Alumina (Al_2O_3)	..	2·76	0·24	Nil	0·40	0·10	0·15	..
Ferric oxide (Fe_2O_3) ..	..	0·15	0·23	Nil				
Ferrous oxide (FeO) ..	..	..	..	Nil	..	..	..	0·27
Manganous oxide (MnO) ..	Nil	0·07	0·10	1·10	3·20	1·88	1·78	..
Lime (CaO)	55·56	30·65	53·71	55·25	53·35	47·58	44·50	39·20
Magnesia (MgO)	..	0·56	0·20	0·20	0·15	0·25	0·15	1·10
Carbonic anhydride (CO_2) ..	43·67	23·85	41·30	42·71	42·25	37·70	35·58	30·35
Moisture and organic matter	0·04	..	..	0·26	..	0·39	0·44	0·62
	100·00	97·99	100·00	100·00	100·00	100·00	100·00	100·00

References.—(1) From Komata Reefs Mine, according to N.Z. Geol. Surv. Bull. No. 15, 1912, p. 106. Analyst, R. J. Morgan. A pencil note made by Mr. C. Fraser on a copy of the analysis attached to a Geological Survey file ascribes the sample to Walker's Maratoto Mine.

(2) Carbonate from Maratoto Claim, Maratoto. Date of analysis, 1911. Lab. No. B 206.

(3) Carbonate from Golden Cross Mine, Waitekauri. Date of analysis, 1911. Lab. No. B 208.

(4) From No. 5 level, Waihi Mine. Date of analysis, 1911. Lab. No. A 1015.

(5) Empire lode, No. 5 level, Waihi Grand Junction Mine.

(6) Martha lode, No. 9 level, Waihi Mine.

(7) Martha lode, No. 5 level, Waihi Grand Junction Mine.

(8) Maria lode, intermediate level, 81 ft. below No. 14 level, Talisman Mine. N.Z. Geol. Surv. Bull. No. 16, 1913, p. 105, and Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 779.

Nos. 5, 6, and 7 are quoted from N.Z. Geol. Surv. Bull. No. 15, 1912, p. 133. Lab. Nos. A 1039/1, 2, 3.

Summary of Limestone Resources and of Means of Transport.

Other than the calcitic lodes of the gold-mining areas, and whatever shells may be on the coast-line or in Maori middens, Ohinemuri has no lime deposits, and must depend on other parts of New Zealand for supplies. The means of transport to the agricultural areas may be considered as good. In the east the ports of Whangamata and Bowentown (Katikati Heads) are a little to the north and south respectively of the coast-line of the county; and a branch railway, now being continued to Tauranga, reaches Waihi. The middle part of the county is traversed by a railway and the navigable water of the Thames River. A loop-line from Paeroa west-north-west to the Main Trunk line at or near Pokeno is contemplated, and will undoubtedly be constructed within a few years. In many places the roads need improving, but the eastern part of the county, at any rate, has inexhaustible supplies of good roadmaking material.

Literature.

Practically the whole of Ohinemuri County has been geologically surveyed in detail. The results, together with excellent topographical and geological maps, are embodied in Geological Survey bulletins Nos. 10 and 15 (previously mentioned by title), and in Bulletin No. 16, "The Geology of the Aroha Subdivision, Hauraki, Auckland," 1913, written by J. Henderson, assisted by J. A. Bartrum. These three bulletins give long lists of previous publications dealing with the geology and mineral resources of the areas described. The publications that have since appeared need not be enumerated here.

17. RAGLAN COUNTY.

The geology of Raglan County is fairly simple, but has not been worked out in detail, and therefore can be only roughly indicated. A belt of Early Mesozoic and perhaps in part older rocks (greywacke and argillite) extends from Taupiri in the direction of Kawhia, and sends off an arm into the central part of the county. South of Waikato Heads are Neocomian (Early Cretaceous) sandstones and shales, perhaps underlain by older rocks. A great part of the county is covered by a series of Tertiary rocks, with valuable brown-coal seams near the base in some places, above which come claystones, greensands or sandstones, and beds of limestone or highly calcareous sandstone, usually thick, followed by thick calcareous claystones of the character commonly called " papa " throughout the North Island. These upper claystones may be correlated with the Waitemata beds of the counties to the north. At Onewhero, and thence north and north-east to the Waikato, the Tertiary marine strata are for the most part covered by a tolerably thick layer of decomposed volcanic tuff. There are also flows of volcanic rock in the district. Mount Karioi in the south-west, between Whaingaroa and Aotea harbours, Mount Pirongia in the south-east (partly in Kawhia County), and perhaps other hills in the south are of volcanic origin. These mountains are believed to be much older than the Auckland volcanic cones, and were probably formed at some time in the Middle Tertiary. In the south-eastern part of the county are the Waipa River flats; and north of the Taupiri Gorge, near the Waikato River, is a plain covered by pumiceous sands or by the " plastic sands and clays " of Hochstetter, Hutton, and Cox. Here are several shallow lakes--Whangape, Roto Ngaro, and Wahi. This plain, or at least that part of it near Huntly, is underlain by coal-seams, and these appear on the surface westward at Pukemiro and many miles southward at Te Akatea. That part of the county immediately inland of the west coast north of Whaingaroa Harbour is very little known from a geological point of view.

The Tertiary limestone mentioned above contains inexhaustible supplies of carbonate of lime, but the grade varies greatly. On the north side of Aotea Harbour, near Whaingaroa Harbour, and north at Te Hara Point, the quality is believed to be excellent. West of the Waipa River, near Karamu and Waingaro, much of the limestone is arenaceous or sandy, whilst the great belt extending northward from the Pukemiro district to near Onewhero is, as a rule, of low grade, and in places is almost a calcareous sandstone. The scattered outcrops of limestone along the coast north from Te Hara Point to Waikato Heads are thin and impure. It is, in fact, somewhat doubtful if this limestone belongs to the same horizon as that of Whaingaroa Harbour. (See Hutton, 1867 report, and in vol. 3 of Trans. N.Z. Inst., 1871; Cox, 1877 reports; and p. 99 of this bulletin, for information relating to the existence of two limestones, or a limestone and a calcareous sandstone.)

Cox's geological map of 1877 shows a considerable area of limestone north of the entrance to Whaingaroa Harbour, at Taranaki Point, and to the north-east a more or less continuous band on the north side of the harbour. The thickness of this limestone is not given in the geological reports consulted, but it is probably 150 ft. or perhaps more. At Te Hara Point, some miles to the north, the limestone has a thickness of 100 ft. to 120 ft., but to the north is said to thin out. It is here, according to Hutton, a hard crystalline flaggy rock, composed largely of rolled fragments of shells and corals (probably not true corals, but Bryozoa). No analyses of the limestone from the Aotea district or Te Hara Point have been found.

The following ten analyses are all attributed to the Raglan district:—

	(1)	(2)
Matter insoluble in acid (sand and clay)	6·36	10·9
Soluble silica	5·51	..
Alumina	0·62	..
Iron oxide	0·41	..
Calcium carbonate	84·75	82·3
Magnesium carbonate	2·35	3·6
Iron-pyrites	..	3·2
	100·00	100·0

(3) to (9) Calcium carbonate (per cent.) 41·00(?), 30·00(?), 94·45, 35·14, 88·14, 61·35, 69·80.

(10) Calcium carbonate, 42·50 per cent.; phosphoric anhydride, 6·21 per cent., equivalent to tricalcic phosphate, 13·57 per cent.

References.—(1) Compact Raglan limestone. Col. Mus. and Lab. 26th Ann. Rep., 1892, p. 48. Lab. No. 5613. The stone represented by this sample and No. 2 were at one time used for making lime.

(2) Same reference as No. 1. Lab. No. 5728 (but see also p. 29). Described as "calcareous mudstone," whereas it is evidently argillaceous limestone. On page 29 it is called a calcareous sandstone. The presence of 3·20 per cent. of iron-pyrites is noteworthy. Forwarded by Mr. Norman R. King. (See pp. 29, 51.)

(3) to (9) From Raglan. Aston, B. C., in Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 237. Analyst's numbers, H 29, H 30, H 251, H 252, H 253, H 254, K 2178. Date, 1907.

(10) Fossiliferous limestone from Te Akau (north of entrance to Whaingaroa Harbour), forwarded by J. J. Craig (Limited). Dom. Lab. 50th Ann. Rep., 1917, p. 22. Lab. No. G 137/2. (See also Chapter V, Part II.)

The variable results of the analyses given above indicate that the Raglan limestones need to be carefully and systematically sampled, in conjunction with a more or less detailed geological survey.

Limestone, thin and apparently of poor quality, outcrops at several points along the coast north of Te Hara Point. The localities mentioned by Hutton and Cox are Otehe or Otahe Point and Waikawau. Near Waikato South Head the limestone is said to be only 6 ft. thick, and of poor quality.

The following analyses of the limestone in the belt west of the Waipa River valley are available:—

A. *From Karamu.*

	(1)	(2)	(3)
Matter insoluble in acid	46·22	44·80	10·31
Alumina and iron oxide	3·20	3·16	1·42
Calcium carbonate	47·33	48·37	88·14
Magnesium carbonate and undetermined	3·25	3·67	0·13
	100·00	100·00	100·00
Quicklime in calcined stone (per cent.)	..	..	81

References.—(1) to (3) From Karamu, forwarded by New Zealand Farmers' Union. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. Nos. E 227/1, 2, 3.

B. *From Waingaro.*

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid	..	..	36·38	42·16	48·29	2·04
Alumina and iron oxide	..	..	3·80	3·84	4·10	0·32
Calcium carbonate	83·91	63·54	57·46	51·95	45·14	97·38
Magnesium carbonate and undetermined	..	..	2·36	2·05	2·47	0·26
	..	..	100·00	100·00	100·00	100·00
Quicklime in calcined stone (per cent.)	..	..	..	..	..	95

References.—(1) (2) From Waingaro district, forwarded by Dr. Makgill. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. Nos. A 11/1, 4.

(3) to (6) From Waingaro, forwarded by C. A. Knowles. Dom. Lab. 48th Ann. Rep., 1915, p. 21. Lab. Nos. 1544/1, 2, 3, 4. The report quoted gives the locality as " Waingaro, Waikato," but there is no post-office of that name in Waikato County, and no limestone is known to occur there. Reference to the New Zealand Post Office Directory for 1918 does not help to clear up the matter, for there is no one with the name of C. A. Knowles in the Waingaro district, and two farmers in the alphabetical list with that name both live in North Auckland. This apparently trivial matter is discussed here because it illustrates the difficulty that may arise in tracing the locality of a sample with an imperfect record, and because analysis No. 6 represents a high-grade valuable limestone, the exact whereabouts of which it is most desirable to know.

The limestone outcropping some miles west of Huntly, near Pukemiro, and thence extending north and south, forms a bold scarp facing east that is visible from many miles away. In general it appears to be of poor quality, and in places is almost a calcareous sandstone. Hand-specimens show that it is a yellowish, arenaceous, but not very hard stone.

Some distance south of Onewhero, a township near the lower reaches of the Waikato, rather poor limestone of greyish-white colour outcrops in the gullies. It is overlain by soft calcareous claystone. The same class of stone is fairly well exposed at various points on or near the road up the Opuatia Valley, south-west of Onewhero. The following analyses of samples of limestone and calcareous claystones from the Pukemiro and Opuatia districts are available :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Matter insoluble in acid ..	5·00	40·73	..	8·74	47·92	45·38	34·80
Alumina and iron oxide ..	1·20	3·50	..	2·05	3·65	5·46	..
Calcium carbonate	91·67	54·91	54·40	85·74	45·49	39·18	57·73
Magnesium carbonate ..	..	0·86	..	..	..	9·98*	..
Phosphoric anhydride ..	..	..	4·85†	..	..	..	0·13
	97·87	100·00	..	96·53	97·06	100·00	..
Quicklime in calcined stone (per cent.)	89 or more	40	..	77 or more	32	25	..

	(8)	(9)	(10)	(11)	(12)	(13)
Matter insoluble in acid ..	40·38	35·96	55·12	11·12	28·75	46·57
Alumina and iron oxide ..	..	..	..	1·68	2·62	1·10
Calcium carbonate	50·75	56·23	27·91	85·47	64·97	50·39
Magnesium carbonate ..	..	..	..	1·12	1·81	1·94
Phosphoric anhydride ..	0·17	0·17	0·12	..	..	..
	..	..	..	99·39	98·15	100·00

References.—(1) From " Huntly," forwarded by J. Furniss, per Director of Fields Division, Agricultural Department. Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 974.

(2) From " Huntly," forwarded by E. Sefton. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 1035. This and No. 1 sample are no doubt from the district west of Huntly. Huntly itself is in Waikato County, but there is no limestone near it on the east side of the Waikato River.

(3) Phosphatic impure limestone from Onewhero Parish, forwarded by Messrs. J. J. Craig (Limited). Dom. Lab. 43rd Ann. Rep., 1910, p. 13. Lab. No. 2233. The phosphoric anhydride in this sample is equivalent to 10·60 per cent. of tricalcic phosphate. If found in quantity the stone would be locally valuable as a fertilizer. The sample was collected some distance south of Onewhero by Mr. A. Thompson, now of Kaipara Flats.

(4) From Onewhero, forwarded by Mr. H. W. Parsons. Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 604.

(5) From Onewhero, forwarded by Mr. H. W. Parsons. Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 984.

(6) From Opuatia, forwarded by H. Murray. Dom. Lab. 47th Ann. Rep., 1914, p. 27. Lab. No. D 686. The sample was perhaps a highly calcareous claystone, not a limestone.

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* Includes moisture 6·28 per cent., and undetermined.

† Equivalent to tricalcic phosphate 10·60 per cent.

This is indicated by the amount of insoluble matter and of water present. Compare with No. 10, and also with No. 2 below.

(7) (8) Impure arenaceous argillaceous limestone from gully on west side of road south of Opuatia Stream, and past 12½-mile peg on road from Tuakau. Lab. Nos. F 124 and F 125. Samples collected by P. G. Morgan in January, 1915.

(9) Similar rock to Nos. 7 and 8, collected by P. G. Morgan in January, 1915, from road up Opuatia Valley (locality north-west of that of samples (7) and (8)). Lab. No. F 126.

(10) Calcareous claystone on road to Onewhero, south of Waikato River bridge, collected by P. G. Morgan in January, 1915. Lab. No. F 127.

(11) Shelly limestone from the bank of the Waikato River, forwarded by R. R. Hunt. Col. Mus. and Lab. 8th Ann. Rep., 1873, pp. 15–16, and 9th Ann. Rep., 1874, p. 17. Lab. No. 1405. Pale buff to red colour, hard, coherent. Hygroscopic water, 1·8 per cent.

(12) Same locality and collector as No. 11. Col. Mus. and Lab. 9th Ann. Rep., 1874, p. 17. Lab. No. 1451.

(13) Calcareous freestone from Waikato district, forwarded by Mr. S. Baker. Fine-grained and compact. Same reference as No. 12. Lab. No. 1553.

The localities given for Nos. 11, 12, and 13 are indefinite, but they are assigned to Raglan as the most likely county.

The following fairly complete analyses of two impure limestones (arenaceous and argillaceous) from Awaroa, west of Huntly, are quoted separately, so that the results may not be tangled by tabulating them with less detailed analyses. The samples were forwarded to the Geological Survey in January, 1916, by Mr. W. J. Ralph:—

	(1)	(2)
Silica (SiO_2)	41·32	22·52
Alumina (Al_2O_3)	7·42	5·28
Iron oxide (Fe_2O_3)	2·08	1·84
Lime (CaO)	23·73	36·28
Magnesia (MgO)	0·33	0·23
Carbonic anhydride (CO_2)*	17·72	27·24
Moisture and organic matter	5·65	5·09
Phosphoric anhydride (P_2O_5)	0·11	0·17
Alkalies and undetermined	1·64	1·35
	100·00	100·00
*Equivalent to calcium carbonate ($CaCO_3$)	40·27	61·91

Reference.—Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. Nos. G 42 and G 43.

Sample G 43 when calcined would have the following composition (unpublished part of analysis):—

Silica (SiO_2)	33·28
Alumina (Al_2O_3)	7·80
Iron oxide (Fe_2O_3)	2·72
Lime (CaO)	53·62
Magnesia (MgO)	0·34
Phosphoric anhydride (P_2O_5)	0·25
Alkalies and undetermined	1·99
	100·00

Further analyses of limestones from Te Mata, Raglan, Waingaro, and Karamu are given by B. C. Aston in the *Journal of Agriculture*, August, 1918 (as previously cited), pages 99, 100.

Summary of Limestone Resources and of Means of Transport.

As previously stated, Raglan County appears to contain large quantities of limestone, but the quality varies. The eastern part, flanked by the Waikato River and the Main Trunk Railway, with short branch lines to Pukemiro and Te Akatea, has good transport facilities. Only a small area in the north could conveniently be served with lime by way of the Waikato River and Port Waikato. In the south-west of the county are Whaingaroa and Aotea, both land-locked harbours of the same type as Kawhia, Manukau, and Kaipara harbours, but much smaller than the last two, and, so far as known, not accessible to large vessels. Raglan, however, is visited regularly by small steamers. The entrance to Aotea Harbour is impeded by sandbanks, and, according to Hochstetter, is not navigable for vessels of any great size.*

The greater part of Raglan County from the Waikato and Waipa flats to the sea consists of hilly country, and at the present time is poorly roaded. Interior transport facilities are therefore for the most part somewhat bad.

Literature.

The chief references to Raglan County in the geological literature are—

Hochstetter's "New Zealand," English translation, 1867, pp. 273–79, 319–24, &c.

Rep. of Geol. Explor., No. 2, 1867, parts of pp. 1–8 ("On the Lower Waikato District," F. W. Hutton); No. 9, 1877, parts of pp. 9–16; No. 10, 1877, parts of pp. vii–viii, xv, 11–26, 123–25; No. 17, 1886, pp. 141–47; No. 21, 1892, pp. 160–61.

Trans. N.Z. Inst., vol. 2, 1870, pp. 169–73; vol. 3, 1871, parts of pp. 244–49; vol. 26, 1894, a small part of pp. 398–407 (Waikato River).

9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, parts of pp. 86–89; 10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, p. 31 (Huntly district).

18. WAIKATO COUNTY.

A very large portion of Waikato County is low-lying, and is covered by the alluvial deposits of the Waikato River, ancient and modern. These form the central Waikato Plains, &c., and consist largely of pumice. There are numerous lakes, the largest of which is Waikare, and several large swampy areas which are gradually being reclaimed. From Taupiri Gorge a ridge of Early Mesozoic rocks trends north-east, and junctions with the similar area west of Ohinemuri County. At Huntly brown-coal seams overlain by claystones, calcareous in their upper layers, occur, and these rocks continue northward towards the Mercer district. No limestone is known to outcrop in the county, and analyses of stone recorded as from Huntly or Taupiri probably all refer to material from Raglan County.

Means of Transport.

Waikato County has rather good means of communication. The Main Trunk Railway and the Waikato River skirt its western side. The southern part of the county is traversed by the Frankton–Morrinsville–Rotorua Railway, and by a branch line from Ruakura to Cambridge. When the loop-line from Paeroa (Ohinemuri County) to Pokeno is made, and the roads are improved, needful supplies of lime will be readily transported to all parts of the county. So far as can be seen, these will come mainly from Waitomo County. From Te Kuiti to Frankton Junction by rail is forty-one miles, to Cambridge is fifty-seven miles, and to Mercer (in Franklin County) is eighty-three miles. Thus all parts of Waikato County are within the 100-mile railway radius from Te Kuiti, which is at present the chief lime-producing locality in the central part of the North Island.

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* "The New Zealand Pilot," 1856, states that the least depth of water on the bar at the entrance to Whaingaroa Harbour is 9 ft., low-water spring tides; and at the entrance to Aotea Harbour, 11 ft., low water. Range of tides, 12 ft. Whaingaroa Harbour is now usually called Raglan Harbour.

Literature.

No part of Waikato County except the Huntly district has been examined in detail by the Geological Survey. The following publications contain the chief references to the geology of the county. Special attention is drawn to the excellent papers by L. Cussen in Trans. N.Z. Inst., vols. 21, 26. These papers, although not invariably correct in theory, embody a large amount of careful observation bearing on the ancient history of the Waikato River.

Hochstetter's "New Zealand," English translation, 1867, pp. 62, 63, 296–314, &c.

Rep. of Geol. Explor., No. 2, 1867, pp. 1–8; No. 7, 1872, p. 116; No. 9, 1877, part of pp. 9–16; No. 10, 1877, parts of pp. xiv–xv, 11–26, 114–28; No. 21, 1892, p. 167.

Trans. N.Z. Inst., vol. 3, 1871, part of pp. 244–49; vol. 21, 1889, pp. 406–16; vol. 26, 1894, pp. 398–407; vol. 47, 1915, pp. 613–14.

10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, p. 31 (with map of Huntly district).

19. PIAKO COUNTY.

In general the geology of Piako County is similar to that of Waikato. It consists largely of the southern part of the Piako or Hauraki Plain, drained by the Piako and Waihou rivers. There are probably areas of volcanic rock in the southern part of the county, and in the north-west are one or two patches of andesitic rocks. In the extreme east of the county volcanic rocks of Tertiary age are found forming the Karangahake-Te Aroha Range, which is a continuation of the Coromandel or Cape Colville Range. A low range of Early Mesozoic rocks forms the Hangawera Hills in the north-west. The county has no limestone, and must depend upon outside sources for lime, which, like Waikato, it probably needs in great quantities.

Means of Transport.

Means of communication may be considered good. The county is traversed by the Morrinsville – Te Aroha – Thames Railway and by the Frankton–Rotorua line, while there is water carriage up the Waihou or Thames River to Te Aroha. Owing to the general flatness of the county there is little difficulty, other than that caused by swamps, in making roads. The volcanic rocks on the eastern boundary of the county can supply unlimited quantities of good roadmaking material. Lime-supplies will probably come from Waitomo County. From Te Kuiti to Morrinsville by rail is fifty-nine miles, to Te Aroha, on the north-eastern boundary, seventy-one miles, and to Waharoa, on the southern boundary, seventy-four miles.

Literature.

The northern and eastern parts of Piako County have been surveyed in detail, and the results will be found in N.Z. Geol. Surv. Bull. No. 16, 1913, previously mentioned under the heading of "Ohinemuri County." The bulletin contains a list of publications, many of which deal with the Te Aroha – Waiorongomai mining district. The following references may be given:—

Hochstetter's "New Zealand," English translation, 1867, pp. 446–47, &c.

Rep. of Geol. Explor., No. 14, 1882, pp. 96–97; No. 15, 1883, parts of pp. xi–xv, 4–51; No. 21, 1892, p. 160.

Cussen's paper in vol. 26 of Trans. N.Z. Inst. should also be consulted.

20. TAURANGA COUNTY.

The hilly parts of Tauranga County consist of volcanic rocks—andesites, rhyolites, and breccias—of somewhat varying age. The lowlands, mostly near the coast, are covered by Late Pliocene, Pleistocene, and Recent deposits largely formed of volcanic débris. On the coast-line are sandhills covering in all about twenty-two square miles. These are best developed on Matakana Island, which forms the outer boundary of Tauranga Harbour. In places the Pliocene beds contain lignite seams. Tauranga County has no limestone, and therefore must depend on outside sources for its supplies of lime, except for what may be furnished by shelly deposits in Tauranga Harbour and along the coast-line. There is deep water at both entrances to Tauranga Harbour, especially the south-eastern one, and when the railways now under construction in the county are completed the chief agricultural districts will possess good means of communication. The hilly volcanic country may be expected to furnish abundant supplies of fairly good stone for roadmaking.

Literature.

The northern part of Tauranga County and a considerable area near Te Puke have been geologically surveyed in detail. The results of the surveys are contained in N.Z. Geol. Surv. bulletins Nos. 15 (only a very small area is dealt with) and 16, and in " The Geology of the Te Puke District," by J. A. Bartrum, in 7th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.-2, 1913, pp. 133–42.

Other publications having reference to the geology of the county are—

Hochstetter's " New Zealand," English translation, 1867, pp. 436–47, &c.

Rep. of Geol. Explor., No. 10, 1877, p. 108 (Tauranga Brown Sands); No. 18, 1887, p. 252 (Dust from Tarawera Eruption); No. 21, 1892, p. 166 (brief outline of geology). The references in the reports cited are of the scantiest.

McKay, Alex.: " Report on the Geology of the Cape Colville Peninsula, Auckland." Parl Paper C.-9, 1897 (bound with Mines Rep.). See pp. 68, 70, 73, and one or two other places. The northern part of Tauranga County is geologically mapped.

McKay, Alex.: " Report on the Te Puke Goldfield, Tauranga County." Part of Parl. Paper C.-9, 1898 (bound with Mines Rep.), pp. 6–7.

McKay, Alex.: " Report on Auriferous Cements at Te Puke, Tauranga County, Auckland." Part of Parl. Paper C.-9, 1899 (bound with Mines Rep.), pp. 26–28.

Other literature relating to Tauranga County is cited in N.Z. Geol. Surv. Bull. No. 16, and in J. A. Bartrum's report of 1913, mentioned above.

21. KAWHIA COUNTY.

The geology of Kawhia County is similar to that of Raglan County. The irregular upland country forming the watershed between the Waipa and Upper Mokau rivers and the coast is largely composed of Early Mesozoic (Trias-Jura) rocks, more or less capped by the Tertiary rocks mentioned below. In places, especially on the south side of the entrance to Kawhia Harbour, Late Jurassic or Early Cretaceous rocks appear. These are moderately fossiliferous, and contain numerous calcareous concretions. Lying unconformably on the Mesozoic rocks is the Tertiary formation in which the Waikato brown coals are found. In the Awaroa watershed near Kawhia, near Te Rau-a-moa, in the Hauturu district, which is partly in Waitomo County, and perhaps elsewhere, coal occurs, but apparently in a somewhat patchy way. Above the coal horizon claystone, and limestone overlain by calcareous sandstone and more claystone (calcareous), appear. These rocks are well developed in the Kawhia Harbour district. Blown sands occur along the coast-line north and south of Kawhia Harbour. Volcanic rock (probably andesite) forms Orangiwhao (Rangiohau of McKay's report) and other hills near Albatross Point, and a belt of volcanic tufa, agglomerate, &c., extends from the andesitic mass of Mount Pirongia down the Oparau Valley to the shore of Kawhia Harbour (Hochstetter and McKay).

Great bodies of hard subcrystalline limestone hundreds of feet thick exist on both the north and south sides of Kawhia Harbour. There are many caves, one of which, Te-ana-hohonu (the deep cave), was visited by Hochstetter. Others were formerly Maori burial-places. McKay[*] states that on the south-east side of the harbour limestone occurs on both sides of the Rakanui Stream, and on the Awaroa River extends from Hautapu Hill east and south-east to the watershed on the east boundary of the county. The available literature does not make it clear whether or not this limestone belt actually junctions with that in which the Waitomo caves occur. According to McKay[†] there are two small outliers of limestone on the south side of Kawhia Harbour, west of Takatahi—one at Totara Point, and the other on the narrow neck of land joining Te Mika Peninsula to the mainland. On the north side of Kawhia Harbour limestone is seen at Te Wharu Bay and Motutara Point, and thence extends north-north-east towards the southern and the eastern shores of Aotea Harbour, where it may possibly pass into the calcareous sandstone seen by Hochstetter at Orotangi and Puketoa cliffs.[‡]

Calcareous breccia grit with oolitic concretions similar to those seen in the Whangarei limestone near Kamo occurs at Puti Point, east of the mouth of Mangara Creek.[§] McKay[||] states that on the coast, towards Albatross Point, thin irregular beds of compact dark-grey or dark-blue limestone occur in a rock-series of Triassic age.

In the above description of the geology and limestone occurrences of Kawhia County some error may well be present. The same remark applies to what has been said about Raglan County. The literature upon which the description depends is very confusing in its references to the calcareous rocks termed by the various writers the Kawhia limestone and the Aotea sandstone. Much exploration is needed in order to define the limestone areas of Kawhia County, and at the same time to ascertain its coal possibilities.

The following analyses of limestone from Kawhia County have been published:—

	(1)	(2)	(3)	(4)	(5)
Matter insoluble in acid..	2·21	..	..	3·61	18·11
Alumina and iron oxide..	0·80	..	..	0·96	1·82
Calcium carbonate ..	93·21	93·50	86·50	95·26	79·51
Magnesium carbonate ..	0·15	..	..	0·17	0·56
	96·37	..	..	100·00	100·00
Quicklime in calcined stone (per cent.) ..	94	89	78·2	92	70

	(6)	(7)	(8)	(9)	(10)
Matter insoluble in acid..	44·59	47·18	48·05	4·58	4·38
Alumina and iron oxide..	2·76	2·54	3·28	0·40	1·57
Calcium carbonate ..	51·66	49·83	42·96	87·71	(92·32)
Magnesium carbonate ..	0·99	0·45	5·71	7·31	(0·95)
	100·00	100·00	100·00	100·00	99·22
Quicklime in calcined stone (per cent.) ..	..	..	..	80	89·0

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[*] Rep. of Geol. Explor., No. 16, 1884, p. 142.

[†] Report just cited, p. 147.

[‡] "New Zealand," English translation, 1867, p. 324.

[§] McKay: Report cited, p. 141. See also p. 120 of volume (rather than p. 119, as cited by McKay).

[||] McKay: Report cited, p. 147.

References.—(1) From Kawhia. Aston, B. C., Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 238. Analyst's number and date, J 150, 1908.

(2) (3) From Kawhia, forwarded by C. S. McLean. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. Nos. G 1404/1, 2. G 1404/2 was a finely crystalline compact limestone, light-grey in colour, apparently suited for use as a building-stone.

(4) From Oparau. Same reference as (1). Analyst's number and date, G 228, 1915.

(5) From Hauturu (near mouth of Awaroa Stream), forwarded by W. H. Armstrong. Dom. Lab. 48th Ann. Rep., 1915, p. 21. Lab. No. E 1216.

(6) (7) (8) (9) From Te Rau-a-moa. Same reference as Nos. 1 and 4. Analyst's numbers and date, G 233/1, 2, 3, 4, 1915. Three of these samples are very poor, and if they had been roughly tested by the collector with hydrochloric acid, as described on page 19, the analyses, so far as they were required to determine the value of the stone for agricultural purposes, would have been unnecessary. No. 9 is a good limestone, and information as to the exact locality and the quantity of the material it represents is desirable.

(10) From Kawhia Harbour (probably quarry at lime-works, Hauturu). Sample collected by Mr. Frank Reed at New Plymouth. Lab. No. H 2550/4. The proper statement of the analysis is as follows: Silica, 4·38; alumina, 1·57; lime, 51·70; magnesia, 0·45; loss on ignition, 41·90; total, 100·00. Dom. Lab. 51st Ann. Rep., 1918, p. 36.

A sample of rock forwarded in 1914 from Koropupu (probably near Te Rau-a-moa) by Mr. C. J. Honoré contained 30·72 per cent. of calcium carbonate and 0·24 per cent. of phosphoric anhydride. (Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 998). This sample, although classed by the analyst under limestones, probably represented a highly calcareous claystone, and in any case cannot be called a limestone. (See his remarks on its fertilizing-value.)

Summary of Limestone Resources and of Means of Transport.

Kawhia County appears to have abundant supplies of excellent limestone, together with a great deal of poorer material, which is perhaps to be described as calcareous sandstone. Exploration and geological mapping, as previously stated, are badly needed. Except for such facilities as are offered by Aotea and Kawhia harbours, with the tidal creeks connected with them, means of transport for heavy goods are poor. A railway has been surveyed from the Main Trunk line to Kawhia, and when made will open up the northern part of the county. The county is hilly, and as yet has poor roads, but is well supplied with roadmaking material.

A plant for pulverizing limestone was erected at Hauturu, near Kawhia, a year or two ago, but at the time of writing no information concerning it has been obtained. A reference to the plant (which apparently includes a lime-kiln) appears on page 416 of vol. 14 of the *Journal of Agriculture* (May number), 1917.

Literature.

Among the chief references to the geology of Kawhia County are the following:—

- Hochstetter's "New Zealand," English translation, 1867, pp. 324–32. The limestone near Kawhia Harbour is described and illustrated on pp. 328–29.
- Hutton, F. W., in Trans. N.Z. Inst., vol. 3, 1871, pp. 244–49.
- Rep. of Geol. Explor., No. 2, 1867, part of pp. 1–8; No. 9, 1877, part of pp. 9–16; No. 10, 1877, part of pp. 10–26 (see especially p. 25); No. 16, 1884, pp. xxxiv–xxxviii, 140–48 (see especially map and pp. 141, 142, 147); No. 17, 1886, part of pp. 136–40; No. 21, 1892, pp. 156–57.

22. WAIPA COUNTY.

Waipa County lies between the Waikato and Waipa rivers, and is almost wholly included in the middle Waikato Plain. Its geology is similar to that of Waikato County, and need not be further described. There are no limestone deposits, and the county must depend on outside sources for its lime.* It is traversed by the Main Trunk Railway, and therefore supplies of lime can conveniently be introduced. From Te Kuiti, which has lime-making and limestone-crushing plants, to Te Awamutu, just inside the south boundary of the county, is twenty-six miles, and to Frankton Junction, on the north-east boundary, is another fifteen miles. A branch railway reaches Cambridge, which is on the north-east boundary; and from Ngaruawahia, in the extreme north of the county, a branch railway runs to Glen Massey (Waipa Collieries), in Raglan County, a locality not far from the limestone belt west of Waipa River. Hence, when its roads have been macadamized throughout, Waipa County will have no difficulty in obtaining and distributing lime-supplies.

Literature.

Some of the leading references to the geology of Waipa County are—

Hochstetter's "New Zealand," English edition, 1867, pp. 305–19, 453–56, &c.
Rep. of Geol. Explor., No. 2, 1867, pp. 2, 7, 8; No. 9, 1877, part of pp. 9–16; No. 10, 1877, part of pp. 11–26; No. 17, 1886, part of pp. 136–40; No. 21, 1892, p. 170.

The papers of Cussen in Trans. N.Z. Inst., vols. 21, 1889, pp. 406–16, and 26, 1894, pp. 398–407, should also be consulted.

23. MATAMATA COUNTY.

A considerable area of flat or nearly flat country occurs round Matamata Township and farther south, in the upper watersheds of the Waihou and Piako rivers. If the volcanic origin of the material of widespread pumiceous deposits sorted by the action of the Waikato and other streams be taken into account, almost the whole surface of the county may be considered as formed of volcanic rocks. Early Mesozoic argillite and greywacke are exposed at the eastern end of the Maungatautari gorge of the Waikato River, and a patch of the same rocks is said to outcrop some miles west of Putaruru Railway-station. No limestone has been found in the county.

Means of Transport.

The Frankton–Rotorua Railway passes through Matamata County, and at Putaruru a privately-owned branch has been made through the southern part of the county to near Lake Taupo. There are therefore good facilities for the introduction of lime to the more settled parts of Matamata County, but the railway haulages will be long. Putaruru is about a hundred miles from Te Kuiti by rail, and the extreme southern and south-eastern parts of the county are eighteen to twenty-five miles farther away.

Literature, &c.

A small area in the extreme north of Matamata County, included in Wairere Survey District, has been geologically surveyed in detail. The results are embodied in N.Z. Geol. Surv. Bull. No. 16, 1913. Other references to the geology of Matamata County are—

Hochstetter's "New Zealand," 1867, pp. 448–52, &c.
McKay, Alex.: "Report on the Pumice-stone Deposits of the Middle Part of the North Island." Parl. Paper C.–9, 1899 (bound with Mines Rep.), pp. 16–25. Portions of this report have reference to Matamata County.

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* In the Jour. of Agri., vol. 17, No. 2, Aug., 1918, p. 99, B. C. Aston lists three samples of limestone from "Hamilton." These must have come from some locality many miles from that town.

Trans. N.Z. Inst., vol. 21, 1889, pp. 406–16, and vol. 26, 1894, pp. 398–407 (Cussen's papers cited on former pages).

11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1917, p. 7 and map at end.

Henderson, J.: "Notes on the Geology of the Waikato Valley near Maungatautari." N.Z. Jour. Sci. and Tech., vol. 1, No. 1, Jan. 1918, pp. 56–60.

24. ROTORUA COUNTY.

With the exception of superficial deposits, the rocks of Rotorua County appear to be wholly of volcanic origin, and therefore no limestone need be expected to occur within its boundaries. The only railway that enters the county is that from Frankton Junction to Rotorua. Hence at present only the Mamaku–Rotorua district can receive lime by rail, and even for this area the railway haulage from limestone districts is long. From Te Kuiti to Mamaku is 118 miles, and to Rotorua another twelve or thirteen miles. How far railways to be constructed in the future will shorten the railway haulage can only be conjectured.

Literature.

Among the chief references to the geology of Rotorua County are the following:—

Hochstetter's "New Zealand," pp. 403–35.

Rep. of Geol. Explor., No. 18, 1887, pp. 240–53 (Tarawera eruption).

McKay, Alex.: C.–9, 1889, as cited under "Matamata."

Trans. N.Z. Inst., vol. 19, 1887, pp. 342–74 (papers on Tarawera eruption—see also pp. 382–84); vol. 20, 1888, pp. 274–82 (Tarawera eruption); Cussen's papers in vols. 21 and 26 already cited.

Hutton, F. W.: "Report on the Tarawera Volcanic District," 1887.

Thomas, A. P. W.: "Report on the Eruption of Tarawera and Rotomahana, N.Z.," 1888.

No attempt is made to give a complete list of the literature relating to the eruption of Mount Tarawera on the 10th June, 1886. There are numerous publications dealing with the hot springs, geysers, and scenery of the Rotorua district. Some of these refer also to the general geology of the surrounding country.

25. WHAKATANE COUNTY.

Very little geological exploration has been done in Whakatane County, which includes a large area of country extending from the Bay of Plenty far inland to Lake Waikaremoana. According to McKay's mapping (see 1887 and 1895 references given below), behind the sand-dunes of the coast-line are fertile alluvial flats and terraces reaching far up the Rangitaiki and Whakatane valleys. Volcanic rocks occupy the whole of the county west of the Rangitaiki River, and another large area of similar rocks occurs between the Rangitaiki and Whakatane rivers. A mass of Early Mesozoic rocks is represented by McKay as occupying a great part of the Urewera country in the interior, and this sends off a narrow strip to the coast at Whakatane. In the far south of the county, according to McKay, beds of white compact limestone occur; and boulders of this rock were observed by him in the bed of Okahu Stream, five miles east of Ahikereru, an old mission station south of Te Whaiti (1887 report, p. 217). A few miles south-east of Ruatahuna a large area of Tertiary rocks (considered by McKay to be Cretaceous) is entered. This extends far to the north-east and south-west, and is in fact continuous with the Tertiary rocks of the Gisborne and Hawke's Bay districts. A limestone belt begins a few miles south-west of Maungapohatu Mountain, and extends many miles to the north-east. According to McKay the limestone is of a coralline character, and apparently the beds alternate with strata of a marly character. He was not allowed by the Maoris to examine the sacred mountain Maungapohatu, where, in a great fissure or cave, " the remains of all the notable dead of the Urewera country are deposited " (report of 1895, p. 164).

No other limestone is known to occur in Whakatane County, but there may possibly be calcareous bands in the Mesozoic rocks, and probably there are workable shell deposits on the coast or at the river-mouths.

The following two analyses of calcareous rocks from Whakatane County have been published :—

	(1)	(2)
Matter insoluble in acid (silica, &c.)	3·02	..
Alumina and iron oxide	1·79	..
Calcium carbonate	92·30	28·75
Magnesium carbonate	2·78	..
Water	0·11	..
	100·00	..
Quicklime in calcined stone (per cent.)	89	..

References.—(1) Limestone from Kuaotunu, Urewera County, forwarded by the Hon. R. J. Seddon. Col. Lab. 28th Ann. Rep., 1894, p. 14. Lab. No. 6571. This sample probably represents the limestone from Maungapohatu Mountain or its near neighbourhood.

(2) From Waingarara, Taneatua, forwarded by P. Pederson in 1914. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. No. E 806. This analysis cannot be said to represent a limestone. The exact nature of the stone analysed is not stated.

Summary of Limestone Resources and of Means of Transport.

Whakatane County has poor lime resources, and is in a bad position for obtaining supplies from other parts of New Zealand. The river ports of Matata and Whakatane admit only small vessels. The Tauranga – Te Puke Railway will ultimately be continued along the coast through Whakatane County to Opotiki. This, however, will not tap any limestone deposits, but will merely enable imported lime to be conveniently distributed from the various Bay of Plenty ports throughout the coastal belt.

Literature.

The chief references to the geology of Whakatane County are—

Rep. of Geol. Explor., No. 18, 1887, part of pp. 193–219. See also geological map opposite p. 192.

Mines Rep., Parl. Paper C.–3, 1895, pp. 157–65, with map (Urewera country).

Mines Rep., contained in Parl. Paper C.–9, 1899, part of pp. 16–25.

2nd Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1908, pp. 9–10.

26. OPOTIKI COUNTY.

The geology of Opotiki County is not at all well known, but in a general way is similar to that of Whakatane County. There is a coastal plain from the hills west of Ohiwa Harbour to some miles east of Opotiki. South of this is a belt of volcanic rocks, ending a few miles east of Opotiki. Old Mesozoic rocks, in continuation of those of Whakatane, form almost the whole interior and north-eastern part of the county (a rugged semi-mountainous area), but the Tertiary (or Cretaceous) rocks of the Maungapohatu district extend into the southern part, and these contain the chief limestone strata known to occur in the county. At Te Kaha, about half-way between Opotiki and Cape Runaway, the Mesozoic (or possibly Palæozoic) rocks contain " nodules of blue limestone and thin veins of calc-spar " (McKay, 1887 report, p. 217).

These, and similar occurrences in the Mesozoic rocks elsewhere, are probably of little value as sources of lime.

In the extreme north-east of Opotiki County a small patch of fossiliferous limestone of Middle or Upper Tertiary age occurs on the coast between Te Keru Creek and Kotiki or Oteki Point. According to McKay, Tertiary limestone covers a considerable area in the Waikura Valley, and is developed towards the base of the Tertiary series between the Waikura and Raukokore River north of Kaikoura Peak, at the east end of Kaikoura Range (see 1887 report, p. 209).

The only published analyses of limestone from Opotiki County are two that are reported as from Opouae, but are no doubt from Oponae, a remote settlement in the south of the county near the Maungapohatu limestone belt. These analyses are as follow :—

	(1)	(2)
Silica	..	38·93
Alumina and iron oxide	..	3·80
Calcium carbonate	97·95	56·36
Phosphoric anhydride	0·12	0·18
Moisture and organic matter	..	0·73
	..	100·00

Reference.—From " Opouae " (? Oponae), forwarded by W. McLean. Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 67/1, 2. No description of the samples is given. No. 2 is highly siliceous, but No. 1 is almost pure carbonate of lime, and perhaps represents a vein of calcite. No such name as " Opouae " can be found on the map of Opotiki County, or in reference lists, but there is an " Oponae," and the fact that the name of W. McLean, a farmer, is given by the New Zealand Post Office Directory as that of a resident practically proves that Oponae is the address of the sender of the samples. The samples may have come from the Maungapohatu limestone belt, or may have come from calcareous bands in the Mesozoic rocks of southern Opotiki.

Summary of Limestone Resources and of Means of Transport.

From the above paragraphs it will be seen that Opotiki County is very poorly supplied with limestone deposits, and those that do exist are in remote, little-known localities. The agricultural parts of the county on or near the coast will therefore either have to import lime or depend upon such supplies as may be obtained from shell deposits. As regards means of communication, Opotiki County is in much the same position as Whakatane. The East Coast or Bay of Plenty Railway is to be made to Opotiki, as mentioned under " Whakatane County," and ultimately may be continued through the rough inland country to connect with the Gisborne-Motuhora Railway.

Literature.

The principal references in the scanty literature to the geology of Opotiki County are—

Rep. of Geol. Explor., No. 5, 1869, pp. 7, 8, and map opposite p. 8 ; No. 10, 1877, pp. 107–13 ; No. 18, 1887, part of pp. 193–219.

Mines Rep., Parl. Paper C.–3, 1895, part of pp. 157–65, and map therewith.

27. WAIAPU COUNTY.

A patch of Trias-Jura rocks occurs at Te Koau or Iron Point, near Hicks Bay ; and rocks of the same age perhaps form more of the Raukumara Range on the western boundary of Waiapu County than is shown by McKay in his map of the " North-east District of the North Island " (1887 report, opposite p. 192). The greater part of Waiapu County, however, is covered by rocks of probable Cretaceous age. Some of these rocks may be Late Jurassic. They consist of conglomerate, sandstone, claystone, limestone, &c., and occur over a wide inland belt, which reaches the coast from the mouth of the Waiapu River to south of Tuparoa. Miocene sandstones and claystones occupy the East Cape district from Te Araroa to the mouth of the Waiapu River, and are seen again on the coast north and south of Waipiro, and inland from Tokomaru to the Mata River valley. The lower part of the Waiapu River flows through a wide valley covered by alluvial deposits, and there are also one or two river-flats, such as that of the Awatere. West of Te Awaroa is a small coastal plain. From Cape Runaway to Matakaoa Point is a narrow belt of volcanic rocks (diabase, agglomerate, &c.). South of this is a strip of Upper Tertiary rocks which, near Whangaparaoa, according to Cox, contain some limestone.

The Cretaceous and Miocene rocks mentioned above are calcareous throughout, but are not known to contain any well-defined limestone stratum unless it be a chalky limestone in the Cretaceous group, believed to correspond with the Amuri limestone of the South Island. McKay, in his report of 1887, mentions chalky limestone or chalk marl as seen (1) between Rocky Point and Awatere (south of Awanui), (2) between Awatere and Roporua (Reporua), (3) at Takoratea Hill, and (4) south of Akuaku. Bituminous limestone was seen (1) underlying the chalk marls between Awatere and Reporua, (2) between Akuaku and Reporua, (3) between Akuaku and the source of the Whareponga, and (4) inland from Tuparoa. In his report of 1887 McKay states that limestone corresponding physically, chemically, and geologically to the Amuri limestone is seen (1) on the Mata River, twelve miles south of Hikurangi; (2) a little to the south of Waipiro; and (3) between Whareponga and Tuparoa. In his report of 1901 he states that thin beds of yellow limestone, full of fossils, occur a little inland of Waipiro or Open Bay.

The Cretaceous rocks almost everywhere contain calcareous concretions, and McKay in his various reports mentions many localities where cone-in-cone limestone occurs.

The Miocene rocks of Waiapu County, though everywhere calcareous, and usually concretionary, contain hardly any layers that can be called limestone. McKay states that highly calcareous rocks occur at Akuaku and thence north to Whareponga, and on the south-west side of Tokomaru Bay, but nowhere else between Poverty Bay and the East Cape.

The bold headland or peninsula known as Te Koau Point, on the south side of Hicks Bay, has a somewhat complicated geological structure, and quite a number of different rocks are present.* Among these is an impure, shelly, pebbly limestone, which is best seen on the track leading over the headland from Te Araroa (Kawakawa) to Hicks Bay. Marshall states that it is interbedded with tuff and scoriaceous material (1914 paper, p. 284). Limestone may occur in the strip of Tertiary rocks south of the Matakaoa – Cape Runaway volcanic belt, but reliable oral information is to the effect that the rocks of this locality are mainly sandstone. As previously mentioned, a little limestone occurs near Whangaparaoa. The blue sandy marls or calcareous claystones in this district, like similar rocks elsewhere in the North Island, are locally called " papa " or " papa rock." Speaking of this Cox prophetically remarks, " I would call attention to the fact that this term is not applied to the Leda marls alone, but also to any greasy beds which at all resemble them, so that much confusion may arise from the name " (1877 report, p. 109).

No analyses of limestone or of any highly calcareous rock occurring in Waiapu County have been found in the literature. The county is badly supplied with high-grade limestone fit for " burning," but in many places there are soft marly rocks that may be used as soil-dressings where lime is required. It has no good port, but there are numerous landing-places along the coast, of which Tokomaru, Waipiro, and Te Araroa are the most important. Internal communications are somewhat poor, and there are as yet no roads suitable for the transport of heavy goods throughout the year. Owing to the hilly nature of the country railway-construction will be difficult.

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* Marshall's account in vol. 46 of Trans. N.Z. Inst., p. 284, is incomplete.

Literature.

The chief references to the geology of Waiapu County are the following :—

Rep. of Geol. Explor., No. 5, 1869, pp. 7, 8, and map; No. 8, 1877, part of pp. xvi–xx, and greater part of pp. 121–52; No. 10, 1877, part of pp. 107–13; No. 18, 1887, parts of pp. xxviii–xxxix, 193–219; No. 21, 1892, part of pp. 151–52 (under the heading of "Cook County," which in former years included Waikohu and Waiapu counties).

8th Ann. Rep. N.Z. Geol. Surv., App. C. to Parl. Paper C.–2, 1914, part of pp. 124–28. (Second edition, 1915.)

Col. Mus. and Lab. 2nd Ann. Rep., 1867, pp. 25–28 (see also pp. 20–25).

Parl. Paper C.–10, 1901 (bound with Mines Rep.), part of pp. 21–25.

Trans. N.Z. Inst., vol. 39, 1907, part of pp. 509–20; vol. 46, 1914, pp. 283–85.

28. Waikohu County.

The geology of Waikohu County is similar to that of Waiapu. Jurassic or Trias-Jura rocks are seen at Motuhora Mountain, a few miles south of Motu. Cretaceous claystones, sandstones, and limestones continuous with the Cretaceous rocks of Waiapu form a fairly wide belt on the north-western side of the county, and an outlying patch appears near the Whatatutu oil-springs. The eastern portions of the county are almost wholly covered by Tertiary sandstones, claystones, and limestones. Pleistocene material forms a few patches on some of the flatter ridges, and Recent alluvium forms a thin coat over the various river-flats.

The Cretaceous limestone is a dense, hard, light-coloured rock, usually much shattered, which generally has a somewhat chalky appearance. For the most part, veinlets of calcite with thicknesses varying from that of a sheet of paper to 3 in., fill the joints. It is a prominent rock in the basins of the Mangatu and Upper Waipaoa rivers, where it forms a large part of the eastern flank of the Raukumara Range. In the hilly country east of the mountains it appears in the Waipaoa River less than two miles above Whatatutu, and outcrops irregularly along the valley of the Mangataikapua Stream. Large boulders entangled in a great fault-zone occur still farther eastward in the Makahakaha–Ngarara Stream. In places a rock that was originally limestone has been wholly or partly silicified, and is now valueless as a source of lime (see N.Z. Geol. Surv. Bull. No. 9, 1910, p. 14). The following analyses show the composition of the Cretaceous limestones :—

	(1)	(2)	(3)
Silica	5·40	20·52	11·55
Alumina	0·48	6·28	2·81
Ferric oxide	0·96	1·92	1·28
Lime	50·78	37·25	45·56
Magnesia	0·60	0·10	0·50
Carbon dioxide	39·90	29·30	35·80
Moisture	0·40	3·30	1·60
Organic matter	Nil		
Alkalies and undetermined	1·48	1·33	0·90
	100·00	100·00	100·00
Calcium carbonate (by calculation, per cent.)	89·18	66·34	80·11
Ditto, by addition of CaO and CO_2	90·68	66·55	81·36

References.—(1) From Makahakaha–Ngarara Stream, above confluence with Melissa Stream. N.Z. Geol. Surv. Bull. No. 9, 1910, p. 44, and Dom. Lab. 43rd Ann. Rep., 1910, p. 12. Lab. No. 2599.

(2) From Slip Stream, a small tributary of the Waipaoa, entering two miles above Whatatutu. Same references as (1), but p. 11 of Lab. Rep. Lab. No. 2317/3.

(3) From Waipaoa River, between first and second road-crossings above Mangataikapua homestead (or about one mile and a half above Whatatutu). N.Z. Geol. Surv. Bull. No. 9, p. 44, and Dom. Lab. 42nd Ann. Rep., 1909, p. 20. Lab. No. 1816.

A sample of limestone sent by Mr. H. E. Burgess from Matawai in 1908 to the Dominion Laboratory was found to contain 54·94 per cent. of lime and 43·16 per cent. of carbon dioxide, making by addition 98·10 per cent. of calcium carbonate. No limestone is known to occur near Matawai, and the specimen, which is unusually pure, no doubt either came from some other district or represents a calcite vein. (Dom. Lab. 42nd Ann. Rep., 1909, p. 21; Lab. No. 2075.)

Tertiary limestone of good quality forms the summit of Saxby Hill, a small hill north-west of Whatatutu on the east side of the Waipaoa River. Various other outcrops of Tertiary limestone are in places difficult of access, such as the summit of Wheturau Hill, six miles and a half north of Whatatutu, where limestone 15 ft. in thickness extends along the ridge from trig. station 138 westward for a few chains. In the bed of the Waipaoa River, opposite Waipaoa homestead, a band of limestone 3 in. or 4 in. thick is interbedded with argillaceous sandstone and claystone. Similar bands about 10 ft. in thickness occur on the crest of the ridge separating the Waipaoa River and the Mangaorongo Stream, slightly south of east from the mouth of the Weraroa Stream, and also on the crest of the same ridge about a mile farther eastward. South of Mangatu Survey District limestone is exposed on the hill between the Waikohu and Waihuka rivers. The Tertiary limestones of Mangatu Survey District are described by Adams as fairly crystalline in character, with a greenish tint. They contain numerous shell-fragments and a very small amount of sand (N.Z. Geol. Surv. Bull. No. 9, 1910, p. 17).

The Saxby Hill limestone has the following composition :—

Silica	3·05
Alumina	7·44
Ferric oxide	1·14
Lime	47·24
Magnesia	0·25
Carbon dioxide	37·12
Moisture and organic matter	3·73
Alkalies and undetermined	0·03
	100·00
Calcium carbonate by addition of lime and carbon dioxide (per cent.)	84·36

Reference. — Coralline limestone from trig. station A (Saxby Hill), N.Z. Geol. Surv. Bull. No. 9, 1910, p. 44, and Dom. Lab. 43rd Ann. Rep., 1910, p. 11. Lab. No. 2317/2.

" Shelly conglomerate bands occur in the beds of the Waipaoa River, and in the Mangatuamaru, Torekepokia, Mangatawa, and Omega streams. These bands are of a loosely coherent nature, and consist mainly of shells and shell-fragments, with some small pebbles of sandstone and a very small proportion of sandy clay. The average thickness of the bands is about 6 in. and the maximum attained is about 9 in." (J. H. Adams in N.Z. Geol. Surv. Bull. No. 9, p. 17.)

Adams also describes (Bull. No. 9, p. 17) numerous indurated fine-grained bands in the eastern part of Mangatu Survey District and throughout Waingaromia Survey District. These bands are of a concretionary nature, and generally contain a considerable amount of magnesium as well as of calcium carbonate. Concretions of similar composition to these bands are very common in the same areas, but according to Adams are not in the same set of beds as the indurated bands (Bull. No. 9, pp. 15–16).

The calcareous claystones and sandstones of Waikohu County in places contain 20 or 30 per cent. of calcium carbonate. The following analyses are quoted as representative of the concretionary bands and the highly calcareous claystones and sandstones :—

	(1)	(2)	(3)
Silica..	19·65	40·07	52·71
Alumina	9·58	11·90	5·90
Ferric oxide	5·44	1·68	3·36
Ferrous oxide	Nil	..	2·38
Lime	21·55	21·00	15·82
Magnesia	9·28	1·20	1·30
Carbon dioxide	30·05	16·50	18·53*
Phosphoric anhydride	..	0·15	
Combined water and organic matter	1·62	5·10	
Loss at 100° C.	0·93		
Alkalies and undetermined	1·90	2·40	
	100·00	100·00	100·00
Calcium carbonate (by calculation, per cent.)	45·09	34·50	Less than 28·30
Magnesium carbonate (by calculation, per cent.)	19·49	2·52	2·73

References.—(1) Concretionary bands from Mangatawa River, Waingaromia Survey District. Sample collected by J. H. Adams in February, 1908. Lab. No. 248.

(2) Calcareous claystone, or rock intermediate in character between clay-shale and chalky limestone, from Mangapapa Stream below limestone gorge. N.Z. Geol. Surv. Bull. No. 9, 1910, p. 18, and Dom. Lab. 43rd Ann. Rep., 1910, p. 11. Lab. No. 2318/2.

(3) Calcareous green (glauconitic) sandstone from Otoko, forwarded through Geological Survey by Mr. John Tombleson. Dom. Lab. 49th Ann. Rep., 1916, p. 20. Lab. No. F 451.

Other analyses of calcareous rocks will be found in N.Z. Geol. Surv. bulletins Nos. 9 and 21.

Summary of Limestone Resources and of Means of Transport.

Waikohu County appears to have considerable limestone deposits, mostly of medium or low-grade quality, and in districts far from a railway or other convenient means of transport. The south-west part of the county contains some limestone, but has not been geologically explored, and no account of any deposits in that district has been found in the literature consulted. The railway from Gisborne now crosses the county, and at present ends at Motuhora, on the north-west boundary. By means of this railway, lime from some of the localities in Cook County, presently to be described, or from Hawke's Bay can be conveniently brought into the Te Karaka district, where most of the arable land of the county is found. Waikohu County is very hilly, and at present most of the roads are poor or are represented by bridle-tracks.

Literature.

Part of Waikohu County has been geologically surveyed in detail. The results of the surveys are contained in N.Z. Geol. Surv. Bull. No. 9, 1910, and in Bull. No. 21, not published at the time of writing.

Other references to the geology of the county are—

Rep. of Geol. Explor., No. 8, parts of pp. xvi–xx, 159–62; No. 18, 1887, parts of pp. xxxviii, 193–219.

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* Composed of—Potash, 1·98 per cent.; soda, 0·65 per cent.; loss on ignition, 15·90 per cent.

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.-2, 1914, part of pp. 124–31. (Second edition, 1915.)

Parl. Paper C.–10, 1901 (bound in Mines Rep.), pp. 21–25.

Trans. N.Z. Inst., vol. 20, 1888, part of pp. 293–306; vol. 21, 1889, part of pp. 320–25; vol. 39, 1907, part of pp. 509–20.

N.Z. Geol. Surv. bulletins Nos. 9 and 21 contain fuller lists of literature.

29. Cook County.

The rocks of Cook County consist in great part of Cretaceous and Tertiary mudstones and clayey sandstones, all of which on analysis have been found to contain a small percentage of carbonate of lime. On some of the ridges a deposit of pumiceous silt, probably of aerial origin, is found, and alluvial material of no great thickness forms the cover of the fertile Poverty Bay and Tolaga Bay flats. Limestone occurs in the county, but does not cover a large area. There are two limestone formations, the older of which is probably Late Cretaceous in age, and the younger Late Tertiary.

The older limestone, which is usually a hard flaky rock of a light-yellowish colour, is exposed in the north-west corner of the county near the head of the Mata River. The same rock occupies greater areas in the adjoining counties of Waiapu and Waikohu. This limestone, as it occurs in Cook County, may be disregarded as a source of agricultural lime.

The younger limestone covers small irregular areas in the vicinity of the Poverty Bay flats. It occurs typically at Waihirere near Ormond, and therefore is usually termed by geologists the Ormond limestone. It is a moderately soft shell limestone, consisting largely of shell-fragments, which are generally mixed with a considerable proportion of pumice sand and clay. Complete shells also occur, and where these are numerous the rock is harder and of better grade. Such limestone is the best roadmaking material so far used in the Gisborne district, the softer stone, however, being suitable only for spalls. The superimposed beds often show decided changes in composition, and the material in a bed may vary considerably in a few chains. Evidently the limestone was formed in shallow water close to an ancient shore. In Cook County limestone of this type is exposed at several points, and the deposits as far as known are briefly described below.

At Gray's Hill Quarry, four miles south-east of Ormond, a thick massive layer of limestone striking east-north-east and dipping south-south-east at about 30° is quarried for the purpose of making roads. The rock is friable, and probably contains little more than 60 per cent. of calcium carbonate. The deposit is less than three miles from the Poverty Bay flats, but material from the quarry would have to be carted to this, the principal area of arable land in the district, by way of roads of heavy gradients.

The limestone near the Native settlement of Waihirere is better situated, a road leading to the foot of the cliffs which overlook the Waihirere Stream. It lies almost horizontal, and in places is over 80 ft. thick. It does not, however, consist of high-grade material, and the best of it is situated some distance up the stream-valley. Waihirere Railway-station is about three miles by road from the nearest part of the deposit, which extends at least two miles along the main branch of the Waihirere.

The Public Works Department has opened a quarry in limestone a few miles west-south-west from Patutahi, at a point about a mile and a quarter from the Gisborne–Napier Railway, with which it is connected by a branch line. The limestone stratum, which is probably 100 ft. thick, strikes north-north-east and dips westward at about an angle of 45°. It is underlain by fine-grained sandstone containing irregular patches of chalky limestone, and overlain by more sandstone, above which is claystone. Very little overburden has to be removed, and railway-ballast is cheaply produced.

The Cook County Council's quarry is about a mile to the westward of the Public Works quarry described above. It is situated in the valley of a small stream draining northward to the Waikakariki, and is approached by a branch from the main road about 50 chains in length. The limestone band is 50 ft. or more in thickness, and dips westward at from 15° to 20°. It is underlain by blue claystone (" papa "). The rock being quarried is a hard shelly limestone of a blue colour, and is the best roadmaking material in the district. The amount of stripping, 12 ft. to 20 ft. of clay, adds considerably to the working-costs. The area of accessible limestone is not very large.

The Gentle Annie Quarry is situated in the valley of Te Aroha Stream, close to the Gisborne–Tiniroto–Wairoa Road, about five miles south-west of Patutahi. The rock quarried is an extremely shattered rubbly limestone, which varies greatly in composition and general appearance. Although the hard fragments consist of fairly pure limestone, an average sample including the rubble would probably be of very poor quality. The quarry has been worked by the Gisborne Borough Council in order to obtain roadmaking material, but is now abandoned.

Limestone similar to that obtained from the Cook County quarry near Patutahi is broken from a quarry situated on the Gisborne–Tiniroto Road rather less than two miles west of Waerenga-o-kuri. The limestone, which is at least 20 ft. thick, strikes north-east and dips south-eastward at about 40°.

Limestone of poor quality occurs on top of a hill in the Te Arai watershed, three miles and a half south-east of the Gentle Annie Quarry. There is limestone near the head of the Mangapoike, but this has not been examined.

The following analyses of Cook County limestones have been published :—

	(1)	(2)	(3)	(4)	(5)
Silica, or matter insoluble in acid ..	7·93	6·09	9·13	13·74	4·83
Alumina .. .. Ferric oxide.. ..	2·27	1·59	2·14 1·16	2·00	1·90
Titanium	..	..	0·18	..	..
Lime	48·72	50·75	46·91	43·08	(52·28)
Magnesia	0·84	0·87	1·05	3·59	(0·39)
Carbonic anhydride ..	37·68	39·96	35·82	35·49	(41·50)
Water and organic matter	2·59	0·68	2·08	2·47	..
Alkalies	..	..	1·18	..	..
	100·03	99·94	99·65	100·37	100·90
Calcium carbonate (per cent.	83·55	88·64	78·75	71·68	93·36
Magnesium carbonate, &c. (per cent.) ..	1·76	1·83	2·22	7·54	0·81
Quicklime in calcined limestone (per cent.)	81·5	85·6	76	69	88

References.—(1) (2) Public Works quarry (east-south-east of County Council quarry, and one mile south of Repongaere Railway-station).

(3) Cook County Council quarry (over four miles west-south-west of Patutahi). Fairly complete analysis.

(4) Gisborne Borough quarry at Gentle Annie (nearly two miles south of Public Works quarry). This and the three preceding analyses are published in 8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914 (second edition, 1915), and in Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab. Nos. E 101/1, 2, 3, 4 (Nos. 1 and 2 wrongly attributed to County Council quarry). Samples collected by P. G. Morgan.

(5) From " Gisborne." Aston, B. C., in Jour. Agric., vol. 11, Sept., 1915, p. 240.

In the 21st Ann. Rep. of the Col. Mus. and Lab., 1886, p. 38, Skey mentions a sample of shelly limestone from Poverty Bay containing 23·42 per cent. of lime (CaO), and a sample of nearly pure travertine from the same locality containing about 54 per cent. of lime (CaO)—that is to say, over 96 per cent. of carbonate of lime. The samples were forwarded by Mr. Lockie. Lab. Nos. 4169/1, 3.

In Dom. Lab. 45th Ann. Rep., 1915, p. 20, a sample of limestone from Gisborne forwarded by H. Travers is stated to have contained 98 per cent. of calcium carbonate. No limestone of such purity is known in Cook County. The sample was perhaps taken from a calcite vein, or possibly from a travertine deposit. (Lab. No. B 662.)

Analyses recently published by B. C. Aston include: Whakapunake, 48·6 per cent. $CaCO_3$; Wairakaia, 69·1 per cent. $CaCO_3$. (Jour. Agri., vol. 17, Aug., 1918, p. 99.)

Summary of Limestone Resources and of Means of Transport.

Agricultural lime for use on the Poverty Bay flats can be best obtained from the limestone beds of the Waikakariki Valley west-south-west of Patutahi, where the quarries mentioned above have been opened out. Not only is most of the limestone of fair quality suitable either for calcination or pulverization, but it is conveniently situated near a railway. The known deposits are not large, but similar stone probably exists at other points in the locality. The limestone near Waihirere is also worthy of attention, and probably portions will be found of as high grade as the limestone in the Waikakariki Valley.

In the neighbourhood of Tolaga Bay calcareous shelly sandstone is quarried for roadmaking at points about two miles west and five miles north of the township. The rock probably contains less than 50 per cent. of calcium carbonate, and is therefore of little value for agricultural purposes.

Means of communication in Cook County are still far from perfect. Poverty Bay affords good sheltered anchorage for large vessels, except in southerly weather. Tolaga Bay is also a fairly good roadstead. Only small vessels can at present reach the wharves at Gisborne. A railway runs north-west from Gisborne to Motuhora in the west of Waikohu County, and from this a railway intended ultimately to reach Napier branches at Makaraka. The Napier Railway, though made for only a few miles, has already rendered the limestone deposits at Patutahi more accessible, and as it proceeds southward will probably tap other limestone districts. Owing to the scarcity of good macadamizing material the Cook County roads are in general poor, except in the district served by the quarry west of Patutahi.

Literature.

A considerable part of Cook County has been geologically surveyed in detail. A very small area in the north is described in N.Z. Geol. Surv. Bull. No. 9, 1910. Most of the northern and middle portions of the county are mapped and described in Bulletin No. 21, which has not yet been published.

The following publications may also be cited as containing references to the geology of Cook County:—

Rep. of Geol. Explor., No. 5, 1869, part of pp. 7–8; No. 8, 1877, part of pp. xvi–xx, 116–20, 152–59, 162–64; No. 9, 1877, part of pp. 96–105; No. 18, 1887, p. xxxix, part of pp. 193–219; No. 21, pp. 151–52.

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914, part of pp. 124–31. (Second edition, 1915.)

Parl. Paper C.–10, 1901 (bound in Mines Rep.), part of pp. 21–25, with map and sections opposite p. 36.

Trans. N.Z. Inst., vol. 20, 1888, part of pp. 293–306; vol. 21, pp. 318–25; vol. 29, 1897, pp. 567–71; vol. 39, 1907, part of pp. 509–20. These four papers are all by H. Hill.

As a rule only parts of the above reports and papers refer to Cook County. Fuller and more complete lists of literature are given in N.Z. Geol. Surv. Bull. No. 9, and especially in Bull. No. 21.

30. AWAKINO COUNTY.

The geology of Awakino County is similar to that of Kawhia County. Old Mesozoic greywackes and argillites occupy portions of the county, especially in the western part, where they form the Herangi Range. Late Jurassic and Cretaceous rocks also occur. Above these rocks is a series of Tertiary strata, of which an important member is the Te Kuiti limestone. This has a wide distribution in the north-eastern portion of the county, whence it extends southward for many miles down the valley of the Awakino River. This limestone, which in places attains a thickness of 200 ft., is usually separated from the Mesozoic rocks by inconsiderable layers of conglomerate, grit, and claystone. In a few localities it is underlain also by beds of carbonaceous shale and coal. Above the limestone are thick beds of claystone which contain, in some places, two thin bands of limestone. Massive sandstone layers succeed, interbedded with which are several seams of brown coal, usually of no great thickness. These form the Mokau coal-measures. Above them are well-bedded greenish and bluish sandstones. Beds of andesitic tuff of subaqueous origin overlie unconformably. These are everywhere calcareous, and in places pass into limestone. The last-named rock occurs at Tirua Point, on the south side of the Mokau River, and in the Mohakatino Valley. The two latter localities are, however, in Clifton County. Moeatoa and Whareorino, two andesitic mountains near the coast in the north-western portion of the county, were probably the vents from which the ash and lapilli of the tuff-beds were distributed. The limestone strata nearly everywhere are either wholly or in part of excellent quality, so that Awakino County appears to be well supplied with stone fit for the production of lime.

Part of Awakino County has recently been geologically examined by Dr. J. Henderson, Mining Geologist, who has furnished the following preliminary reports on limestone near Mahoenui and Awakino :—

"*Limestone near Mahoenui (between Te Kuiti and Awakino).*

"In the neighbourhood of Mahoenui limestone for agricultural purposes could be obtained from the cliffs showing along the Awakino River, one mile and a half up-stream from the post-office, or at Stony Creek, three miles from the same place, along the Awakino Road. In both localities the rock could be cheaply broken, and power for crushing and pulverizing could be obtained from the streams without great expense. Both localities are approached by a well-graded road, and both could yield very large quantities of stone of the quality shown by the analyses quoted below. At Stony Creek the cliffs are at least 50 ft. high, and the rock is apparently all of a quality similar to that of the sample taken. This contained 98 per cent. of calcium carbonate and only 1·12 per cent. of matter insoluble in acid. Along the Awakino River the cliffs are higher, but the limestone as a whole is of lower grade. The upper layers are at least 20 ft. thick, and consist of greyish-white limestone apparently of better quality than the lower layers. A representative sample on analysis was found to contain 95·4 per cent. of calcium carbonate and 3·29 per cent. of matter insoluble in acid.

"A sample from the more massive underlying portion of the limestone outcropping a few chains farther up-stream, and continuing for half a mile, contained 76·3 per cent. of calcium carbonate and 22·58 per cent. of matter insoluble in acid.

"*Limestone near Awakino Village.*

"On the metal reserve on the right bank of the Awakino, about two miles up-stream from the village and half a mile from the main road, there is an outcrop of limestone at the base of a grass-covered spur. The deposit is at least 20 ft. in thickness, would require little stripping, and is approached by a level road. It contains everywhere numerous pebbles of greywacke up to 3 in. in diameter, and these in places constitute fully one-third of the rock. A sample was taken as free from these pebbles as possible, and was found to contain 93·4 per cent. of calcium carbonate and 5·19 per cent. of matter insoluble in acid. On a working-scale it would be difficult to obtain such a clean rock, but stripping the soil from the hillside may disclose a layer free from pebbles.

"Beside the main road, close to the point where the road to the deposit above described branches off, there is an outcrop of similar rock. Here the greywacke pebbles are very numerous, the rock, in fact, being a conglomerate with a calcareous cement. A thickness of about 6 ft. is exposed, and the bed must be closely overlain by yellow sandstone."

Mr. H. H. Sharp, Public Works Engineer, Stratford, during 1916 reported to the Engineer-in-Chief on limestone in the North Taranaki Land District. He obtained thirteen samples of limestone in or near Awakino County, and these, with a copy of his report, were forwarded to the Geological Survey. The following particulars are obtained from Mr. Sharp's report and by examination of the samples:—

No. 1: Yellowish-white flaggy limestone, hard, compact, and crystalline. Joints, iron-stained. Evidently high grade. On Mangapohue Road, Awakino County, about nine miles from Marakopa. The stone is in an easily accessible position and can be easily quarried. The stripping is about 5 per cent. of the stone to be worked.

Nos. 2 and 3: Yellowish-white hard shelly limestone, irregularly jointed. Joints, iron-stained. Quality of both samples good, especially No. 2. On Mangapohue Road, about one mile and three miles respectively east of No. 1. The road runs through one outcrop and beside the other. Stripping, only about 3 per cent. Many thousands of cubic yards of stone in sight. No. 2 is near Waitomo County boundary. No. 3, so far as can be judged, is in the north-west corner of Waitomo County.

No. 4: Highly arenaceous limestone, or compact calcareous sandstone of light-brownish-white colour. Residue after acid treatment, brown sand, mainly quartz, with a little white mica. On Marakopa River to Mahoenui Road, about seven miles from Marakopa River, from a cliff fully one mile in length and of varying heights up to 300 ft. The rock-face, according to Mr. Sharp, is a mixed sandstone and limestone—that is, arenaceous limestone, like the sample. There is little or no stripping, and the rock can be easily quarried. Unfortunately the sample probably contains barely 50 per cent. of calcium carbonate, and presumably the rock-face itself will be no better.

Nos. 5 and 6: Flaggy yellowish-white iron-stained limestones, both of good quality. No. 6 is more iron-stained and less compact than No. 5. About four and five miles respectively south of No. 4, from cuttings on same road. There is little stripping, and the rock can be easily quarried.

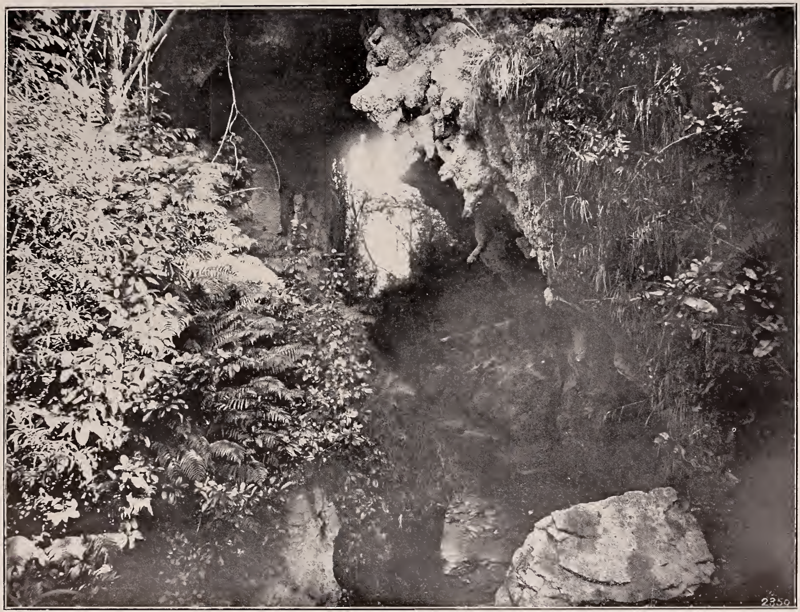
No. 7: Nearly white compact limestone, of good quality. On same road as Nos. 4, 5, and 6, six miles south of No. 4. Rock similar to samples Nos. 2 and 3, but softer (this is not evident in sample). Access good. Stone suitable for quarrying. No stripping.

No. 8: Light-coloured compact arenaceous limestone, with numerous small pebbles of greywacke or similar rock. Near Awakino School. Good access. Stone easily quarried Low-grade rock, though, apart from the pebbles, its quality is fair to good. Sand residue after acid treatment, light brown.

No. 9: Close moderately-fine-grained greyish arenaceous limestone. On Lower Awakino Road. Good access. Stone easily quarried. Treatment with acid shows that the quality is fairly good. The residue consists of light-coloured quartz-grains and a few dark grains. Viewed as a whole it is of light-greenish-grey colour.

No. 10: Close-grained light-coloured limestone of good quality. On Taumatataire Hill, Awakino - Te Kuiti Road. Good access. Easily quarried. After treatment with acid only a little fine greyish sand is left.

PLATE IV.



LIMESTONE CAVE, MAHOENUI, AWAKINO COUNTY.

[*Photo by Tourist Department.*]

No. 11: Bluish or, when slightly weathered, greyish rock with white calcareous spots. Contains many small pebbles of sandstone and other rocks. From Stony Creek, on Awakino – Te Kuiti Road. Good access. Easily quarried. Low grade. This sample is evidently from the lower part of the limestone horizon (see Dr. Henderson's report). Residue from acid treatment consists of small pebbles and dark-coloured sand.

No. 12: Light-coloured shelly limestone, similar to Nos. 2 and 3. Good quality. From west side of Upper Awakino Valley Road, near junction with Te Kuiti Road. Accessible position; stone easily quarried.

No. 13: Bluish-grey calcareous sandstone. From or close to Mangaotaki Stream, on Awakino – Te Kuiti Road. Accessible position; stone easily quarried. Low grade The residue, after the rock is pulverized and treated with acid, is bulky, and consists of dark-coloured sand. The solution contains a good deal of iron.

In each of the six localities Nos. 8 to 13 there are large quantities of limestone. There is no stripping, and the rock can be easily quarried. The cost of quarrying will perhaps be about 2s. 6d. per cubic yard (rock broken to 9 in. cubes). Sample No. 13, however, represents rock that is too low in calcium carbonate to be worth quarrying for agricultural purposes. Samples Nos. 8 and 11 are poor limestones, of little value if better stone can be procured in the neighbourhood.

Nearly all the thirteen samples resemble the Te Kuiti limestone more or less closely. This is true even of the shelly and the arenaceous samples. No. 13 resembles the lower part of the Te Kuiti limestone as seen in the Public Works quarry, but is much lower in calcium carbonate.

Analyses Nos. 1 and 2 of the following table represent limestones from Awakino County (see also analyses quoted by Dr. Henderson on a previous page). In addition there are seven analyses of limestone from the Mokau River, some of which, however, are probably from the Clifton County side of the river (see p. 115).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Matter insoluble in acid ..	7·33	1·80	3·36	5·21	62·20	7·11	10·24	22·00	37·60
Alumina and iron oxide ..	1·50	0·81	3·15	3·49	..	2·21	2·91	2·19	15·40
Calcium carbonate ..	87·41	96·12	90·43	88·09	33·90	88·05	83·93	73·17	40·30
Magnesium carbonate ..	3·64	1·16	2·82	2·97	..	2·39	2·68	2·46	3·11
Alkalies, organic matter, &c.	..	..	..	..	..	..	..	..	3·24
Water	0·12	0·11	0·24	0·24	3·90	0·24	0·24	0·18	0·35
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Quicklime in calcined stone, per cent. (Aston) ..	80	93	85	80	..	80	78	..	..

References.—(1) Calcareous conglomerate, having matrix of white subcrystalline calcium carbonate, from Mr. John Elliott's property, Mahoenui. Forwarded by Hon. R. J. Seddon. Col. Lab. 33rd Ann. Rep., 1900, p. 12. Lab. No. 8558. The analyst remarks that the pebbles are very unevenly dispersed, so that the analysis is only approximately correct. The rock takes a good polish.

(2) Hard, granular, light-grey crystalline limestone from Awakino, forwarded by Mr. E. M. Smith, M.H.R. Col. Lab. 35th Ann. Rep., 1902, p. 9. Lab. No. 9027. Alumina 0·51, iron oxide 0·30 per cent. "It should prove a good building-stone, and an excellent rock for lime-burning."

(3) Semi-crystalline limestone from the vicinity of the Mokau River, forwarded by Mr. J. Rees. Col. Mus. and Lab. 16th Ann. Rep., 1882, pp. 30–31. Lab. No. 2912. Iron oxides predominate over alumina. "It is an excellent stone, fit both for building and ornamental purposes, while the waste or impure parts could be utilized for the preparation of lime."

(4) Compact limestone, and (5) calcareous sandstone, from Mokau, forwarded by Mr. Kennedy Macdonald. Col. Mus. and Lab. 25th Ann. Rep., 1891, pp. 57–58. Lab. Nos. 5394/*a*, *b*.

(6) Light-coloured fine-grained limestone from "Mokau and Mount Smart," forwarded by Mr. E. M. Smith, M.H.R. Col. Lab. 30th Ann. Rep., 1897, p. 10. Lab. Nos. 7020/1, 2.

(7) Brown coarse-grained limestone. Same locality and reference as No. 6. Lab. No. 7020/3.

(8) Dark-grey mottled limestone. Same locality and reference as Nos. 6 and 7. Lab. No. 7020/3.

(9) Fine-grained, hard, compact, bluish-grey argillaceous limestone from Mokau, forwarded by Mr. E. M. Smith, M.H.R. Col. Lab. 35th Ann. Rep., 1902, p. 9. Lab. No. 9026. Alumina in this sample was 11·80 per cent.; oxides of iron, 3·60 per cent. Nos. 6, 7, and 8 are also quoted in Parl. Paper I.–2A, 1911, p. 153, the latter two incorrectly.

Summary of Limestone Resources and of Means of Transport.

As already remarked, Awakino County appears to have excellent limestone resources. Much of the stone is of high grade, and well suited for the production of lime. As yet means of communication are poor. The county has no railway, and many of the formed roads are unmacadamized. Though it has a coast-line of some length, the mouths of the Awakino and Mokau rivers are the only ports where sea-going vessels can enter and depart. The former is navigable by small steamers for about three miles from its mouth. The Mokau forms the southern boundary of the county, and can be ascended by small steamers for a few miles, whilst oil-launches, &c., can proceed some distance farther.

Literature.

A detailed geological survey of the southern part of Awakino County has been made, but as yet no results have been published. The chief references to its geology are the following:—

Rep. of Geol. Explor., No. 12, 1879, pp. 20–22; No. 18, 1887, pp. xlii, 44–47, 68, 177, and casual references on other pages.

4th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1910, part of pp. 5–9.

The literature dealing with Clifton County should also be consulted.

31. WAITOMO COUNTY.

The great series of Early Mesozoic rocks (perhaps in part Palæozoic) that is so well developed in many parts of the North Island outcrops at many places in Waitomo County, but is nowhere prominent. Early Cretaceous (?) rocks appear in the west on the banks of Mangaotaki Stream. The older rocks are overlain by a great series of Tertiary strata, consisting of sandstones with more or less coal, greensands, limestone, and calcareous claystones. West of Te Kuiti these are the main rocks. Volcanic tuff partly masks the Tertiary beds near Te Kuiti and elsewhere in the middle part of the county, and probably covers almost the whole surface in the south-east part of the county except where the old rocks forming the mass of the Rangitoto-Tuhua Range appear. Limestone covers a large area in the neighbourhood of Waitomo caves west of Hangatiki, and thence extends westward into Kawhia County, and intermittently southward to Wairere Falls and the Aria district. It is found along the Kawhia and Awakino County boundaries, where, according to Henderson, it forms a wide belt over twenty miles long on the eastern side of the Tawairoa Range. There are several patches near Te Kuiti, north, south, and east. In the northern part of Waitomo County, some miles south of Mount Pirongia, in the upper valley of the Moakuroroa (or Moakurarua) Stream (a tributary of the Waipa), a considerable area of limestone has been mapped by Park (1886 report, map opposite p. 138). Near Te Rau-a-moa it extends into Kawhia County. No analyses of this limestone are available, unless those of samples from Te Rau-a-moa quoted on page 86 are considered applicable. Some miles farther south is the important area of limestone drained by the Waitomo and other tributaries of the Waipa, which contains the famous Waitomo caves. The limestone, according to Hochstetter, is at least 200 ft. thick, and of high quality; but the only published analysis* is one of a ferriferous magnesian limestone, forwarded to the Dominion Laboratory in 1914 by A. R. Sennett. This is as follows:—

Iron oxides (FeO and Fe_2O_3)	10·13
Lime (CaO)	29·10
Magnesia (MgO)	15·57
Carbonic anhydride (CO_2)	40·00
Moisture and organic matter	1·82
	96·62

Reference.—Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab No. E 204.

The patches of limestone near Te Kuiti are relatively small; but some of them, on account of their high quality and proximity to the railway, are of great importance, and are being quarried for roadmaking, for railway-ballast, and for the manufacture of lime and of ground limestone.

A mile or perhaps more north-north-west of Te Kuiti Railway-station the Borough Council has a quarry in a limestone patch on the west side of the railway and the road. Hard yellowish-white flaggy limestone striking north-west, and dipping at 3½° to the north-east, here forms a face 60 ft. to 70 ft. high. It is of remarkably good quality, as shown by analysis No. 10 in the table below.

To the east and north of the Borough Council quarry similar limestone has been quarried at several places. The most extensive quarries are those worked by Messrs. Wilson (of Wilson's Portland Cement Company) for the manufacture of lime and ground limestone at the neighbouring works. A red-clay loam forms a heavy overburden at the quarries, and fills erosion cavities. The amount of limestone that can be conveniently quarried has been greatly diminished by erosion, and the dip of the limestone to the east also lessens the height of the quarry-faces in that direction. The limestone is hard, yellowish-white, and sparingly fossiliferous so far as large organisms are concerned. A few shells, several species of "shark" teeth, and some mammalian bones (? whale) have been found. No analyses of the stone, as far as known, have been published, but the quality is undoubtedly exceedingly good.

The limestone as broken at the quarries is conveyed to the works by means of a tram-line and an endless chain which drags the trucks along. On reaching the works the stone is broken in a large Gates rock-breaker, and screened into several sizes. The largest size is conveyed to two brick-kilns, which may be, but are not always, operated continuously for the production of quicklime. A disintegrator is used to break up the lumps of quicklime after their discharge from the kiln, and the lime is then bagged for the use of farmers. Some of the quicklime is slaked and sent to the goldfields, where it is used in cyanide plants to neutralize the acidity of the ore or tailings treated therein. A small rock-breaker of the Blake type may be used to reduce medium-size lumps to a smaller size. All small lumps go to pulverizers, which reduce them to powder. This is screened, and the oversize returned to the pulverizer. The final product is a fine white powder with a little grit, which is weighed into fairly small bags holding perhaps 1½ cwt. (weight not ascertained). Steam-power is used for driving the machinery.

The works are very compact; but there is more screening, and especially more elevating, than would be necessary in a perfectly designed plant. The Gates rock-breaker is not worked to anything like its full capacity. A disadvantage is that there is no drying-apparatus, and consequently work is liable to be interrupted by spells of wet weather, when the small stock of broken limestone under cover becomes exhausted.

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* Since this was written B. C. Aston has published an analysis of limestone from the Hangatiki district (Jour. of Agri., vol. 17, No. 2, Aug., 1918, p. 99). The sample contained 70 per cent. of calcium carbonate.

Some miles east of Te Kuiti, near the small Native settlement of Mangarapa, and northward on Section 64D, Rangitoto-Tuhua Block, there are small outliers of limestone of good quality at heights of 600 ft. to 700 ft. above sea-level. The limestone may be 100 ft. thick, and at one spot near Mangarapa was observed to dip at 8° to the south-west. In this part of the Te Kuiti district old Mesozoic argillite and greywacke are not far below the limestone, and at one place not more than 15 ft. or 20 ft. of claystone or shale intervenes. On the roads from Te Kuiti to the localities mentioned above a good deal of limestone can be seen. In some places it is flaggy and of good quality, in others it seems of poor quality. In general, sandstone underlies and bluish calcareous claystone overlies. Much-altered rhyolitic tuff unconformably overlies the claystone.

South of Te Kuiti light-coloured, hard, flaggy limestone of good quality outcrops on both sides of the Mangaokewa Stream for some distance. About a mile south of Te Kuiti on the west side of the Mangaokewa it strikes north and south, and dips at 8° to the westward. Strike and dip, however, vary considerably and erratically in this locality, as is not unusual in many parts of New Zealand both with Tertiary and older rocks.

Near the outcrop just mentioned Messrs. Wilson erected during 1916 a plant for pulverizing limestone. As seen by P. G. Morgan it was incomplete, and consisted of a large iron building containing a boiler, steam-engine, pulverizing-machinery, elevators, screens, &c. The limestone was to be delivered to a large Gates rock-breaker, from which an elevator was to raise the broken rock to a revolving screen. This was to separate the material into dust, a small size, a larger size, 2½ in. size, and oversize. The oversizes were to go to a small rock-breaker of the Blake-Marsden type, and the small sizes to a remodelled "Devil" disintegrator. The description of the plant given here is incomplete, and may be partly incorrect.

A short distance south of Wilson's No. 2 plant is a large quarry in limestone which has been worked for many years. It is owned by the Government and controlled by the Public Works Department. Its function is to supply railway-ballast, and for this purpose a rock-breaking plant has been installed. The face of limestone is probably 200 ft. high, and there is certainly more than that thickness of limestone present. The upper portion is flaggy, light-coloured, and probably of good quality. The lower portion is arenaceous and in general of a bluish-grey colour. Its quality is shown by analysis No. 11 of the table below. Some is rather coarse-grained, of greenish colour, and contains a good deal of glauconite.

Near the railway-line south of Te Kuiti limestone may be seen at intervals for a distance of several miles. Analysis No. 3 of the table below represents limestone from a railway-cutting in this locality.

The composition of the Te Kuiti limestone is shown by the following analyses:—

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid ..	1·69	3·30	3·26	0·69	2·14	2·37
Alumina	1·76	3·11	3·14	0·34	1·86	1·72
Iron oxides	0·21			Traces		
Calcium carbonate ..	93·85	91·05	90·96	95·35	92·66	92·34
Magnesium carbonate ..	2·39	2·41	2·52	3·62	2·76	2·94
Water	0·10	0·13	0·12	Traces	0·21	0·22
	100·00	100·00	100·00	100·00	99·63	99·59
Quicklime in calcined stone (Geol. Surv. and Aston) (per cent)	91·6	87·1	87	92	88	88

	(7)	(8)	(9)	(10)	(11)
Matter insoluble in acid	2·29	1·63	3·51	0·47	18·88
Alumina	Traces	2·03	1·00	..	..
Iron oxides	1·79				
Calcium carbonate	92·78	93·24	95·15	98·97	74·79
Magnesium carbonate	2·93	2·99	0·34	..	..
Water	0·21	0·11	..	..	..
	100·00	100·00	100·00	99·44	93·67
Quicklime in calcined stone (Geol. Surv. and Aston) (per cent.)	89	89	91	98·2	62·4

References.—(1) Dark granular limestone from " cutting at 25 miles, Te Kuiti contract," forwarded by Public Works Department. Col. Mus. and Lab. 22nd Ann. Rep., 1887, pp. 41–42. Lab. No. 4553/1.

(2) Buff-coloured granular limestone from same locality as No. 1. Same reference. Lab. No. 4553/2.

(3) Similar stone to No. 2, from cutting at " 27½ miles, Waititi contract." Same reference as Nos. 1 and 2. Lab. No. 4553/3.

(4) Compact limestone from Te Kuiti, forwarded by J. P. Maxwell, General Manager of Government Railways. Col. Mus. and Lab. 24th Ann. Rep., 1890, p. 27. Lab. No. 5035. A " remarkably pure " limestone.

(5) Subcrystalline close-grained limestone, interior of slate colour, exterior very pale-red, from Te Kuiti, forwarded by the Public Works Department. Col. Lab. 29th Ann. Rep., 1895, pp. 11–12. Lab. No. 6846/1.

(6) Similar to No. 5, but of pale-red colour throughout. Same reference as No. 5. Lab. No. 6846/2.

(7) Compact brown subcrystalline limestone from Te Kuiti, forwarded by B. M. Wilson. Col. Lab. 30th Ann. Rep., 1897, p. 10. Lab. No. 6988. See also Mines Rep., Parl. Paper C.–10A, 1895, p. 3.

(8) Compact limestone from Te Kuiti, forwarded by the Public Works Department. Col. Lab. 30th Ann. Rep., 1897, p. 12. Lab. No. 7302.

(9) Aston, B. C., in Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 238.

(10) Yellowish-white limestone from Te Kuiti Borough quarry, collected by P. G. Morgan. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. 1434/1.

(11) Greenish-grey limestone from Public Works quarry, Te Kuiti. Same reference as No. 10. Lab. No. 1434/2.

The first geologist to visit what is now Waitomo County was the well-known Hochstetter, who was in the district for over a week during April, 1859, and has given a fuller account of its limestone than any subsequent writer. It is therefore worth while to summarize his remarks. The limestone is similar to that of the Kawhia, Aotea, and Whaingaroa districts. From Hangatiki Hochstetter visited a cave four miles to the south-west, situated at the northern foot of a hill formed of tabular limestone at least 200 ft. thick (" New Zealand," p. 337). At the point where the Mangapu River divides into its three main branches (three miles and a half west of Te Kuiti) there is a basin surrounded by towering limestone rocks. Two of the streams, the Mangawhitikau (western branch) and the Mangapu itself (middle branch), issue from caves. The exit of the latter stream from its underground course, said to be four miles long (but as a matter of fact almost exactly two miles), is well named Tenga-nui (long throat). Before passing underground the stream is said to run through a romantic narrow gully in the limestone range Mahihinui, by the pa Pehiop (*sic*). The Mangawhitikau has a similar course. It runs past the pa Nikau through the narrow rocky ravine Huruhuru, and then disappears underground for a distance of one to two miles. The limestone in this district is from 300 ft. to 400 ft. thick (p. 340). Between the west coast and the upper Waipa and Mokau districts it " forms a plateau, rising to a height of 1,000 ft. above the level of the sea, remarkable for subterraneous watercourses, caves, and deep funnel-shaped holes, called by the Natives *tomo*." South of the divide between the Waipa and the Mokau, Hochstetter traversed a grassy limestone country about a mile wide, on which there was no bush or fern. On the south side of this area "sharp rugged limestone rocks, called Terore awairoa, form a small defile." This locality is probably a few miles north of Piopio. In the Mokauiti River valley the limestone, according to Park (1887 report, p. 176), is 60 ft. thick.

The limestone occurrences in various parts of Waitomo County will be best described by quoting from a report addressed by Mr. A. J. Baker, Resident Engineer, Public Works Department, Taumarunui, to the Engineer-in-Chief, Wellington, a copy of which has been supplied to the Geological Survey. Mr. Baker's remarks are substantially as follow :—

"In the Taumarunui Public Works district the limestone deposits are confined to a well-defined area. There is no limestone on the south side of the (upper) Mokau River, except within a radius of three miles of Aria Township in the Mokauiti and Rangikohua valleys. It follows that there is no limestone in the Ohura, Ongarue, and Wanganui valleys. The limestone belt extends to Kawhia Harbour, but I cannot say how far it runs south along the coast. In general the limestone is in large masses, which could be quarried with little or no stripping. The cost of quarrying the stone on a reasonable scale would be 3s. to 3s. 6d. per cubic yard, solid measurement, and in most cases drays or other vehicles could be run right into the working-face. All the limestone in the district is in horizontal or nearly horizontal layers, generally from 3 in. to 8 in. thick. The thickness of the limestone horizon seems to vary from 50 ft. to 200 ft."

Eight samples of limestone obtained by Mr. Baker were forwarded to the Geological Survey. The following particulars are given by him or are obtained by examination of the samples :—

No. 1. Light-greyish-white, very compact, flaggy, high-grade limestone from Totoro Road (north-west of Aria). Distance from railway, twenty-six miles. Good outstanding blocks from 4 in. to 6 in. thick and measuring 1 sq. ft. to 6 sq. ft. can be obtained. Deposit alongside metalled road ; no stripping required.

No. 2. Greyish-white, glistening, very compact, flaggy, high-grade limestone from Wairere Falls, 21½ miles from the railway. Good outstanding blocks from 4 in. to 6 in. thick, and measuring 1 sq. ft. to 4 sq. ft., obtainable. Deposit adjacent to a metalled road ; 1 ft. stripping required. This stone has been tested and found to contain 98·8 per cent. of carbonate of lime. According to Park the limestone at Wairere Falls is 150 ft. thick (1887 report, p. 68).

No. 3. Light-greyish-white, glistening, very compact, flaggy, high-grade limestone from big bluff at Mangaotaki Bridge, near Awakino County boundary, on the Te Kuiti to Mokau Road. Distance from railway, twenty-four miles. Blocks 4 in. to 6 in. thick, measuring 1 sq. ft. to 2 sq. ft., obtainable. Adjacent to metalled road ; practically no stripping required.

No. 4. Light-bluish-grey, very compact, high-grade limestone from the eighteen-mile quarry, eighteen miles from Te Kuiti on road to Awakino, &c. Layers, 2 in. to 1 ft. thick. Slabs 1 sq. ft. to 4 sq. ft. obtainable. Average stripping required, 2 ft. The residue after acid treatment consists of dark-grey fine sand and silt, with a few coarser almost black particles.

No. 5. Light-coloured compact limestone, with brown spots of oxide of iron and iron-stained joint-planes, from the eleven-mile quarry. Distance to railway, 11 miles 57 chains. Layers, 2 in. to 6 in. thick. Slabs of 1 sq. ft. to 4 sq. ft. obtainable. Not well situated for quarrying ; average stripping required, 4 ft.

No. 6. Almost white, very compact, glistening, very high-grade limestone from Borough Council quarry, Te Kuiti. Distance to railway-station, one mile and a half (only a few chains to railway-line). Stone well bedded; layers, 1 in. to 1 ft. thick. Slabs of 1 sq. ft. to 4 sq. ft. obtainable. Average stripping required, 3 ft. See also former paragraphs, and analysis No. 10 on page 105.

No. 7. Consists mainly of a portion of a large oyster or other fossil, to which a little light-coloured, compact, glistening limestone adheres. From Waitomo, seven miles from railway. The deposit yields good outstanding blocks, from 2 in. to 1 ft. thick, measuring 1 sq. ft. to 6 sq. ft. On good metalled road; no stripping required.

No. 8. Nearly white, very compact, glistening, high-grade limestone from Mangapohue Road (near Kawhia County boundary), eighteen miles from railway. Good outstanding blocks, measuring 1 sq. ft. to 6 sq. ft., 4 in. to 6 in. thick, obtainable. On metalled road; no stripping required.

All the deposits represented by the samples are in accessible positions, and, with the exception of No. 5, are well situated for quarrying. In every case the stone is of high grade, and of such a character as to be suitable for calcination if broken to pass, say, a 2½ in. ring. Being hard, the limestone, if pulverized instead of calcined, will probably require to be somewhat finely ground. Most of the deposits will supply stone suitable for ordinary building purposes, provided thick slabs are not required.

Summary of Limestone Resources and of Means of Transport.

Waitomo County is well provided with limestone of the highest grade. Except at Te Kuiti, this has so far been quarried only for making roads. The Main Trunk Railway runs through the county, existing roads are being improved, and new roads are being made. Ultimately Waitomo County will be able to supply very large areas in neighbouring districts with much-needed lime in the form either of quicklime, slaked lime, or carbonate of lime (ground limestone).

Literature.

The chief references to the geology of Waitomo County are—

Hochstetter's "New Zealand," pp. 332–49.

Rep. of Geol. Explor., No. 17, 1886, part of pp. 136–40, and map; No. 18, 1887, pp. xl, xli, 46, 47, 68, 73, 175–77, 182, &c.

Mines Rep., Parl. Paper C.–3, 1892, pp. 106–8 (Park).

Trans. N.Z. Inst., vol. 20, 1888, part of pp. 316-88 (Cussen); vol. 25, 1894, pp. 353–62 (Park); vol. 48, 1916, p. 93 (Te Kuiti limestone).

4th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1910, part of pp. 5–9; 11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1917, p. 7.

N.Z. Journ. Sci. and Tech., vol. 1, No. 2, March, 1918, pp. 112–15 (Henderson). Gives the best available general account of the geology and topography of the Te Kuiti district.

Hochstetter mentions an early paper by Dr. A. Thomson (author of "The Story of New Zealand") dealing with moa-bones found in the Waitomo caves, which were visited by Thomson in October, 1852. The reference given is *Edinburgh New Philosophical Journal*, vol. 56, pp. 268–95.

32. WEST TAUPO COUNTY.

Old Mesozoic rocks occur in and probably form a considerable part of the Tuhua or Hauhangaroa Range, west of Lake Taupo, and its continuation or offshoot to the north-north-west, the Rangitoto Range. It is not definitely known whether any outcrops of the Tertiary sedimentaries with limestone that are so prominent in Waitomo County occur, except in the Ongarue Valley, north of Taumarunui, where calcareous mudstones almost smothered by rhyolitic tuff may be seen in several places. So far as can be ascertained, volcanic rocks and material of volcanic origin cover most of the county, and limestone is not known to exist in any quantity.

A sample of impure limestone forwarded in 1911 from Taumarunui by Mr. J. E. Slattery was found in the Dominion Laboratory to contain 66·10 per cent. of calcium carbonate and 2·56 per cent. of phosphoric anhydride, equivalent to 5·59 per cent. of tricalcic phosphate. Dom. Lab. 45th Ann. Rep., 1912, p. 20.; Lab. No. B 435. In answer to an inquiry, Mr. Slattery states that the sample came from the sunny slope of a hill within the boundaries of the Borough of Taumarunui.

Means of Transport.

The Main Trunk Railway crosses the north-west corner of West Taupo County, and after passing through Waitomo County runs on or close to its western boundary from Waimiha to south of Taumarunui. The adjoining portions of the county are therefore in a good position to be supplied with lime from Waitomo County. Much of the county is almost without inhabitants, and correspondingly lacking in roads.

Literature.

The chief references to the geology of West Taupo County are contained in the following :—

Hochstetter's " New Zealand," pp. 354–59, 452 (west of Maungatautari).

Rep. of Geol. Explor., No. 18, 1887, pp. xl–xlii, pp. 59, 175, 180–82 ; No. 21, 1892, p. 177.

Mines Rep., part of Parl. Paper C.–9, 1899, pp. 16–25.

Trans. N.Z. Inst., vol. 20, 1888, pp. 306–11, 316–32 ; vol. 21, 1889, pp. 339–53, 406–16 ; vol. 26, 1894, pp. 398–407 ; vol. 28, 1896, pp. 681–88 ; vol. 31, 1899, pp. 498–510 ; vol. 37, 1905, pp. 445–64.

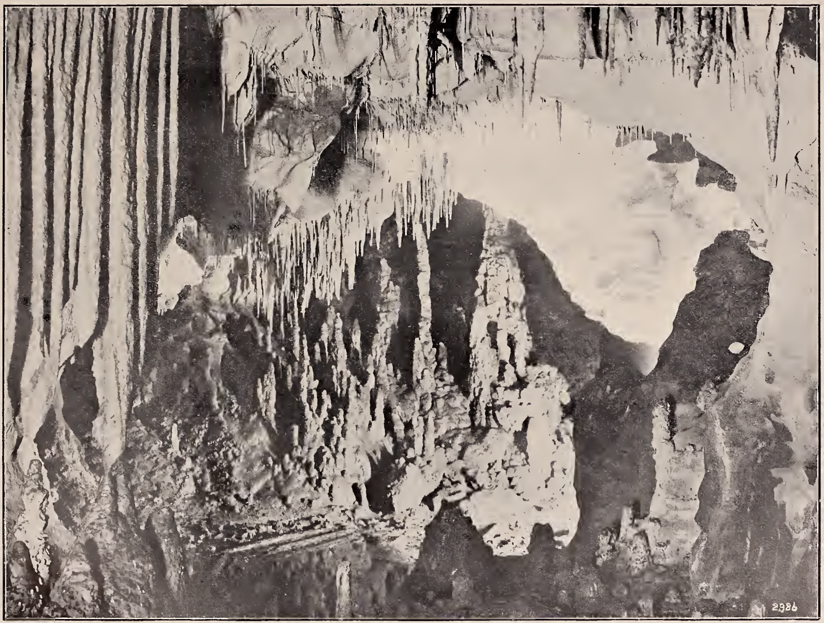
33. EAST TAUPO COUNTY.

The greater part of East Taupo, one of the largest counties in New Zealand, is covered by volcanic rocks, or material (chiefly pumice) of volcanic origin. In the south argillites and greywackes of Mesozoic or possibly in part of Palæozoic age form the Kaimanawa Range. Similar rocks are exposed in the valley of the Waipunga, near Tarawera, on the Napier–Taupo Road. Highly fossiliferous limestone occurs in Te Haroto district, six miles or more south of Tarawera (Hill, 1890 paper, p. 425; 1911 paper, p. 290). It appears that a belt of Pliocene rocks containing some limestone stretches up the Rangitikei Valley, and forms part of the country between the Kaimanawa and Ruahine ranges (Hector, 1871, p. 161). This area is mainly in Rangitikei County (see later pages). More to the north-east, on the borders of Wairoa and Whakatane counties, Miocene or older sedimentary rocks are no doubt present. Limestone has not been definitely reported from that part of the country, but probably does occur.

Means of Transport.

A privately owned light railway beginning at Putaruru enters the north-east corner of East Taupo, but otherwise the county is without railways. Being as yet almost unsettled by Europeans, the county has poor road communications, almost the only roads being those made and maintained for the tourist traffic. A railway from Rotorua will ultimately, no doubt, be made to the Kaingaroa Plains, and may be continued to Lake Taupo, thus opening up a considerable extent of country that needs fertilizers very badly. Lake Taupo itself has some value as a means of communication and transport.

PLATE V.



Stalactites and Stalagmites, Waitomo Caves.

[*Photo by Tourist Department.*]

Literature.

The chief geological references to East Taupo County will be found in the following publications :—

Hochstetter's "New Zealand," pp. 360–402.

Rep. of Geol. Explor., No. 5, pp. i, ii; No. 6, part of pp. 158–64; No. 18, pp. 69–73, and casual references; No. 21, 1892, p. 152.

Mines Rep., Parl. Paper C.–3, 1895. The geological map opposite p. 162 includes a small part of East Taupo County. Mines Rep., Parl. Paper C.–9, 1899, pp. 11–13, 16–25. Mines Rep., Parl. Paper C.–10, 1901, pp. 12–21.

Trans. N.Z. Inst.: All the references given for West Taupo, together with vol. 22, 1890, part of pp. 422–29 (H. Hill), and vol. 43, 1911, pp. 288–96 (Hill).

1st Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1907, p. 6.

Most of the innumerable publications dealing with the Hot Lakes district have more or less reference to East Taupo County. Among the earliest of these are—

Bidwill, J. C.: "Rambles in New Zealand." London, 1841.

Dieffenbach, Ernest: "Travels in New Zealand," vol. 1, 1843, pp. 320–81. Bidwill is quoted on pp. 347–55.

Thomson, Dr. A. S. (author of "The Story of New Zealand," &c.): Article in the *New Zealander* about 1851. Narrates Mr. Dyson's ascent of Ngauruhoe in March, 1851. Quoted by Hochstetter, pp. 373–74.

34. WAIROA COUNTY.

In the extreme west of Wairoa County the Huiarau Range is probably partly composed of Trias-Jura argillites and greywackes, and partly of Cretaceous or younger rocks. A patch of supposed Cretaceous rocks appears in the Morere district, near Mahia Peninsula. Elsewhere, with the exception of a more or less superficial coating of wind-borne pumice and volcanic dust found in many places, and of the alluvial beds near Wairoa, &c., the only rocks seen in the county are of Tertiary age, and, so far as known, include all its limestone. This rock is exposed at many points. Pliocene limestone outcrops at Long Point (Mahia Peninsula), and forms bluffs on the coast-line four miles west of the mouth of the Nuhaka River. Moumoukai Mountain, eastward of the upper Nuhaka Valley, is composed in great part of limestone. Westward of this locality the hilly country drained by the Mangapoike and Makaretu rivers contains massive layers of the same rock. Limestone forms the cliffs in the scenic reserve at Te Reinga. Thence it extends southward towards Wairoa (Clyde), and outcrops three miles west of Frasertown. In 1913 four samples of Wairoa County limestones were forwarded to the Dominion Laboratory by the Fields Division of the Department of Agriculture. Analyses were made and published, but no specific statement as to locality was given. This information, however, together with other valuable particulars given below, was fortunately elicited during 1917 in correspondence between the Mines Department and the Wairoa County Council. The analyses were made by Mr. B. C. Aston, and are as follow :—

	(1)	(2)	(3)	(4)
Matter insoluble in acid	4·42	24·60	24·46	4·48
Iron and aluminium oxides ..	1·00	3·10	2·40	0·90
Calcium carbonate	93·65	69·09	71·24	93·85
Magnesium carbonate, &c. ..	0·93	3·21	1·90	0·77
	100·00	100·00	100·00	100·00
Quicklime in calcined stone (per cent.)	89	55	58	90

Reference.—Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. Nos. D 1216/1–4.

In the course of the correspondence mentioned above a copy of a report by Mr. T. F. Mullaly, Inspector for the Agricultural Department, was forwarded to the Mines Department. Mr. Mullaly in effect states—

No. 1 sample was taken from an outcrop at Te Reinga Falls, twenty-five miles from Wairoa, close to the Gisborne–Tiniroto–Wairoa coach-road, and within a short distance of the projected route of the East Coast Railway. The outcrop is in the Te Reinga Scenic Reserve. Access easy. Unlimited quantities of limestone, apparently of good quality.

No. 2 sample was taken from an outcrop in the Mahaurangi Native Block, near Te Reinga and close to the road. Access is easy. Unlimited quantity of limestone.

No. 3 sample was taken from an outcrop on some Native land at Tahaenui, eighteen miles from Wairoa, and near the Wairoa–Nuhaka Road. The locality is in the centre of a large farming district. Access easy. Large quantities of stone.

No. 4 sample is from the same locality, but a mile farther inland. Access is easy, and the quantity unlimited.

Mr. Mullaly also writes, "The outcrops from which these samples were taken are the most suited for the purpose intended that I am acquainted with in this district, and, if of the desired quality, can be economically worked." Without the information obtained from Mr. Mullaly the analyses quoted above would be valueless for all practical purposes. It may be mentioned that analyses are quoted in this bulletin in many similar cases where necessary data are lacking, in the hope that the exact locality may be known to some reader, and thus additional information of value may ultimately be obtained.

About 1886 Mr. R. Gardiner, of Clyde (Wairoa), forwarded a sample of greyish-coloured stone, which was analysed with the following results:—

Calcium carbonate	53·32
Magnesium carbonate	2·99
Iron oxides soluble in acid	1·63
Alumina	1·43
Siliceous matter	37·81
Water	2·82
	100·00

Reference.—Col. Mus. and Lab. 22nd Ann. Rep., 1887, p. 42. Lab. No. 4464.

Summary of Limestone Resources and of Means of Transport.

With the information to hand it is difficult to say what the limestone resources of Wairoa County are. Good limestone, however, occurs in places; and when the Napier–Gisborne Railway is made the distribution of lime through the county will become a fairly simple matter, for the railway will tap not only the limestone near Te Reinga Falls, but also limestone to the south of the county. The sea carriage of lime to or from Wairoa, and perhaps other points on the coast, is also a possibility. Many of the roads are bad, especially in winter-time, and many prospective roads are not made, but the coming of the railway and the growth of settlement will mend that state of affairs.

Literature.

The chief references to the geology of Wairoa County are to be found in the following publications:—

Rep. of Geol. Explor., No. 9, 1877, pp. 96–105; No. 18, 1887, parts of pp. xxxvii–xxxix, and of pp. 193–219.

Mines Rep., Parl. Paper C.-9, 1899, part of pp. 16–25 (McKay).

Trans. N.Z. Inst., vol. 9, 1877, part of pp. 565–76 (S. P. Smith); vol. 20, 1888, part of pp. 293–306 (H. Hill); vol. 27, 1895, part of pp. 451–66 (Hill), 478–79 (Hill).

35. HAWKE'S BAY COUNTY.

In the west of Hawke's Bay County Trias-Jura argillites and greywackes form the main part of the Ruahine Range. Cretaceous rocks apparently occur at a few places in the central and southern parts of the county, but Late Miocene and Pliocene conglomerates, sandstones, limestones, and claystones are the prevailing surface rocks from the base of the Ruahine Range to the coast, except where the rivers have formed flood-plains. In that part of the county draining to the Rangitikei River, and in the broken mountainous country north-north-west of the Ruahine Range proper drained by the Ngaururoro and other rivers, there are many patches of Tertiary rocks, but how far these would appear connected on a geological map is impossible to say. Pleistocene gravels occur in places, and pumiceous sands or silts (wind-borne in the first place), similar to those of Wairoa County, &c., are of common occurrence. The geological literature relating to Hawke's Bay is fairly voluminous, but difficult to follow, largely owing to the lack of adequate maps. In order to present all the information relating to limestone, a very careful perusal of the literature and much study of maps is required. Hence in the following summary some omissions, either accidental or intentionally made for the sake of brevity, and possibly some errors, may be found by those having the advantage of local knowledge.

Abundant limestone is found in Hawke's Bay, though in all probability it does not outcrop over such large areas as would be inferred from the available maps and the very numerous occurrences mentioned in the literature. All the limestone is of Late Miocene or of Pliocene age, and is known as the Maungaharuru, Te Waka, Pohui, Puketapu, Petane, Scinde Island (Napier), or Te Aute limestone, according to the place of occurrence. The last name is also used as a general term to indicate limestone in other parts of the North Island believed to be of the same age. It is not to be understood, however, that all the limestones just mentioned are necessarily of exactly the same geological age. The Scinde Island or Napier limestone, for example, is believed by McKay to be younger than the Te Aute limestone. Usually the limestone is shelly and somewhat sandy, but in places it is of great purity.

Limestone forms the top and part of the slopes of the Maungaharuru Range in the north of the county. A few miles south it forms the summit of Te Waka or Tikiokura Range, west and south of Pohui. According to McKay the limestone near Pohui is in two bands, with 150 ft. of sandy or argillaceous beds between (1886 report, p. 185). The upper limestone is exposed on both sides of the Pohui branch of the Mangaone Stream for more than a mile to the south-west of the Taupo Road. It outcrops on the hills east of Pohui Lake, where it has a dip of 20° to the east.

Farther south, between Puketitiri and Hawkeston, the limestone in places is full of the shells of a very large oyster (*Ostrea ingens*). Near Patoka is a laminated limestone with very few fossils, resting upon a blue sandy or marly limestone.

More to the south, near the road from Kuripapanga to Moawhango (Rangitikei County), blocks of limestone are seen near the top of the Taruarau Spur, on Otupi (? Otupae) Hill, at a height of about 2,600 ft. Between this place and the Rangitikei River are several scarps of limestone, and the same rock is again seen on the left bank of the river. From Waikonini (twenty-seven miles by road north-west of Napier) towards Kuripapanga there are numerous outliers of limestone forming part of small hills on what is known as the Matapiro and Aorangi Plain (H. Hill, 1890 paper, p. 423). Lenticular masses of limestone, interbedded with blue clays and argillaceous sandstones, appear in Otaharuru Creek, not far from Glenrose homestead. Near Mount Blowhard more limestone is seen. Near a saddle this is fluted in a remarkable manner, like immense organ-pipes.

Limestone in patches appears about half a mile north of the Ngaururoro River, and to the north forms a continuous range, where it is also seen in the valley of Otamauri

Creek. South of the Ngaururoro, limestone occurs near Kereru (in Waipawa County) and forms part of the Whakarara Mountains to the west.

East of the scattered limestone areas in the hilly or mountainous country in the west of Hawke's Bay County there appears to be a belt of country without any limestone to speak of. The eastern part of the county, however, is rich in that rock. Several bands of shelly limestone varying in thickness from 20 ft. upward are developed throughout the hilly country near the coast, from the northern boundary of the county at Waikare River to Napier. Limestone forms part of the high cliff of Tipahanui, and some steep escarpments to the west. Limestone is well developed in the Waipatiki Valley, and to the north and south, at Moeangiangi and Tangoio. In the valley of the Esk River there are two limestone bands, each from 20 ft. to 40 ft. thick, and these are especially well exposed near Petane. At Napier, Bluff Hill or Scinde Island (not an island) is almost entirely composed of calcareous rocks with two distinct limestone horizons. West of Napier limestone is seen at many places—for example, at Puketapu, Wharerangi, and near Woodthorpe (fifteen miles from Napier).

Limestone is exposed on the cliffs about a mile and a half west of Cape Kidnappers, and thence extends south-south-west with little interruption for many miles. It is seen on both sides of the Tutaekuri River at Te Mata, Pakipaki, &c. North of Te Aute (Opapa) the limestone belt crosses to the west of the railway-line, and continues southward into Waipawa County. McKay's geological map of 1877 (opposite p. 68 of report) shows a great extent of limestone, but much of the area ostensibly mapped as limestone is occupied by the associated beds.

About four miles south of Waimarama (Waimirima in old reports) Tertiary limestone caps the coast range, and continues southward into Patangata County. To the north detached masses of the same kind of limestone lie on the surface of supposed Cretaceous rocks. These latter contain calcareous concretions and masses of cone-in-cone limestone.

Analyses.

Many analyses of Hawke's Bay limestones have been published. One or two of the localities from which the samples came have not been certainly identified, but apparently all are in the eastern half of the county, so that the western part is not represented.

Five samples of limestone from Tutira Block, Mangaharuru Survey District, were forwarded to the Dominion Laboratory in 1908 by Mr. W. H. Cooper. The percentage results obtained on analysis were—

	(1)	(2)	(3)	(4)	(5)
Lime (CaO)	52·51	55·14	52·74	54·42	52·58
Carbonic anhydride (CO_2)	41·26	43·32	41·44	42·76	41·32
Calcium carbonate ($CaCO_3$) (by addition of CaO and CO_2)	93·77	98·46	94·18	97·18	93·90
Approximate quicklime in calcined stone (per cent.)	89·4	97·3	90·1	95·2	89·6

Reference.—Dom. Lab. 42nd Ann. Rep. 1908, p. 20. Lab. Nos. 1645/1–5. Phosphate rock may occur in the same locality. (See p. 22 of report cited and Chapter V, Part II of this bulletin.)

The following analyses represent samples supposed to come from Bluff Hill (Scinde Island), Napier :—

	(1)	(2)	(3)
Matter insoluble in acid	11·81	75·98	15.91
Alumina	0·72	1·61	1·06
Iron oxides	0·84	1·30	0·62
Calcium carbonate	84·87	20·71	81·42
Magnesium carbonate	1·76	0·40	0·99
	100·00	100·00	100·00

References.—(1) Shelly coherent limestone from Middle Road.
(2) Calcareous sandstone from Pandora Point.
(3) Compact coarse-grained limestone from Bluff.

These analyses are given in Col. Mus. and Lab. 9th Ann. Rep., 1874, p. 16. Lab. Nos. 1418/8, 9, 10. On page 31 the locality of all the samples is given as "Poukaua Valley, Napier," an address that does not appear to suit any of them. The samples were forwarded by the Superintendent of the Hawke's Bay Province (Hon. J. D. Ormond).

Hector and Skey, in "Reports and Awards of the Jurors, N.Z. Exhibition, 1865," Dunedin, 1866, on pages 393, 448, give analyses and other particulars of two samples of shelly limestones from Napier. One of these contained 91·80 per cent. of calcium carbonate, and the other 81·10 per cent. The full analyses, &c., are quoted in the appendix to Chapter III of this bulletin.

The following analyses represent samples from localities south of Napier :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Matter insoluble in acid	4·06	6·12	4·53	8·55	12·48	10·50	10·96	18·10	..
Alumina	0·46	0·95	0·65	0·30	0·80	1·51	1·54	1·20	4·44
Iron oxides	0·62	0·84	0·46	1·24	0·48	1·01			
Calcium carbonate ..	93·94	90·98	92·85	88·99	85·63	86·04	87·17	76·90	43·75
Magnesium carbonate ..	0·92	1·11	1·51	0·92	0·61	0·94	0·33*	..	0·72
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	96·20	..
Quicklime in calcined stone (B. C. Aston)	90	85	88	81	79	79	88	69	..

References.—(1) Massive but soft limestone from quarry at Pakipaki.
(2) Massive but soft limestone from Pakipaki.
(3) Shelly coarse-grained limestone from quarry twenty miles distant (? from Napier).
(4) Rubbly white limestone with hard nodules from quarry, 24-mile post (? from Napier).
(5) Massive but friable buff-coloured limestone from Te Aute.
(6) Very loose buff-coloured limestone from Te Aute.

The above six analyses are given in Col. Mus. and Lab. 9th Ann. Rep., 1874, p. 16. Lab. Nos. 1418/1, 2, 3, 7, 4, 5. Forwarded by the Superintendent, Hawke's Bay Province (see p. 31 of Lab. report).

(7) Shelly conglomerate from Te Mata, near Havelock North, forwarded by Director, Fields Division, Department of Agriculture. Dom. Lab. 48th Ann. Rep., 1915, p. 21. Lab. No. E 943.

(8) From Te Mata. Aston, B. C., in Jour. Agri., vol. 11, No. 3, Sept., 1915, p. 240. Analyst's number, E 124. Date, 1904.

(9) Shelly conglomerate, Hastings. Aston, B. C., same publication as (8). Analyst's number, K 1418. Date, 1909.

The following three analyses represent highly arenaceous limestone or calcareous sandstone from Cape Kidnappers. They were forwarded to the Colonial Laboratory about 1894 by Mr. S. Carvell, M.H.R., per Mr. J. Aspinall :—

	(1)	(2)	(3)
Calcium carbonate	56·59	52·67	36·73
Magnesium carbonate	2·98	2·99	2·64
Alumina and iron oxide dissolved in acid used	2·14	1·76	2·64
Siliceous matter (almost all sand) ..	36·21	40·46	56·40
Water	0·81	0·71	0·62
Loss	1·27	1·41	0·97
	100·00	100·00	100·00

Reference.—Col. Lab. 29th Ann. Rep., 1895, pp. 10–11. Lab. Nos. 6700/1, 2, 3.

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* Includes undetermined.

The samples represented by the following six analyses came from three localities that have not been certainly identified :—

	(1)	(2)	(3)	(4)	(5)	(6)
Silica..	24·94	..	..	..	..	17·99
Alumina	20·50	..	..	..	..	2·41
Iron oxides	Trace	..	..	..	..	
Calcium carbonate	46·98	57·80	61·21	90·70	92·30	75·39*
Magnesium carbonate	0·74	..	..	..	..	1·64*
Ferrous carbonate	5·56	..	..	..	..	..
Phosphoric anhydride	..	..	..	0·13	0·15	0·14
Moisture and organic matter	..	..	..	..	..	1·24
	98·72	..	..	..	..	98·81
Quicklime in calcined stone (per cent.)	..	..	..	87·9	88·1	..

References.—(1) Soft argillaceous pale-yellow limestone from Pukekura, Hawke's Bay, forwarded by H. Hartree. Col. Mus. and Lab. 24th Ann. Rep., 1890, p. 27. Lab. No. 5099.

(2) (3) Marl from Pukekura, forwarded by H. Hartree. Same report as above, pp. 27–28. Lab. Nos. 5150/1, 2. The residue after acid treatment consists of fine sand and clay.

(4) (5) From Newstead, Napier, forwarded by Land Purchase Commissioners in 1912. Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. Nos. C 644/1, 2. " Well suited for agriculture or building purposes."

(6) From Dunmore, Napier, forwarded by J. S. Dunn. Dom. Lab. 47th Ann Rep., 1914, p. 21. Lab. No. D 204. " When ground to a powder would certainly be valuable to soils requiring lime."

Analyses Nos. 1, 2, and 3 are repeated on a later page, under the heading of "Patangata County," for the reason there given.

Summary of Limestone Resources and of Means of Transport.

Though in places they may be thin or somewhat impure, the limestones of Hawke's Bay County can easily supply all its needs. A railway runs through the county from the port of Napier southwards, and another is in course of construction north to Wairoa and Gisborne. The northern and inland parts of the county are not yet well roaded, but no doubt will be in course of time. At Napier Messrs. Amner and Sons own a plant for the manufacture of quicklime and pulverized limestone, with quarry at the corner of Faraday and Carlyle streets.

Literature.

The chief references to the geology of Hawke's Bay will be found in the following publications :—

Rep. of Geol. Explor., No. 6, 1871, pp. 158–64 ; No. 9, 1877, parts of pp. 43–53, 96–105 ; No. 10, 1877, parts of pp. 67–94 (chiefly pp. 77, 78, 82–85, 88–89, 93–94) ; No. 12, 1879, pp. 64–75 ; No. 17, 1886, pp. 185–92 ; No. 18, 1887, pp. xxxv–xxxviii, 190–208, 211, 217, 218, &c. ; No. 21, 1892, p. 154.

Mines Rep., Parl. Paper C.–9, 1899, part of pp. 16–25 (McKay). Mines Rep., Parl. Paper C.–10, 1901, part of pp. 12–21 (McKay).

Trans. N.Z. Inst., vol. 9, 1877, pp. 565–76 (S. P. Smith) ; vol. 18, 1886, pp. 327–32, 340–42, 343, 367–74, &c. (papers by Hutton) ; vol. 19, 1887, pp. 441–48 (Hill) ; vol. 20, 1888, pp. 282–93, 293–306 (papers by Hill) ;

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* Recalculated from—CaO, 42·19 per cent. ; MgO, 0·78 per cent. ; CO_2, 34·15 per cent. Excess of CO_2, 0·09 per cent.

vol. 21, 1889, pp. 311–18 (A. Hamilton); vol. 22, 1890, pp. 422–38 (Hill); vol. 27, 1895, pp. 451–76 (Hill); vol. 30, 1898, pp. 515–31 (Hill); vol. 32, 1900, pp. 183–88 (Hill); vol. 37, 1905, pp. 431–44 (Hill); vol. 41, 1909, pp. 429–37 (Hill). The numerous papers by H. Hill, though discursive, contain much useful information. Unfortunately in only two papers are maps given by way of illustration, and neither paper happens to deal with limestone deposits in any way except incidentally.

36. Clifton County.

The chief rocks exposed in Clifton County are sedimentary rocks of Tertiary age, varying in age from Miocene or earlier to Late Pliocene. They may be arranged in two groups, which may or may not be separated by an unconformity. The older group, well seen in the Mokau-Mohakatino Block, is to be correlated with the Tertiary sedimentaries of Awakino and Waitomo counties, &c. It consists of sandstones, greensands, claystones, and limestones, with coal-seams in a horizon well above the base of the series, but about 1,000 ft. below the limestone. The younger set of sedimentary rocks consists of pebbly beds, thin shelly conglomerates, sandstones, and claystones. It has a wide distribution in the southern part of the county. Volcanic tuff of andesitic composition thinly covers the surface in the south-west of the county. Rhyolitic tuff similarly occurs in the north-east.

The most promising source of lime in Clifton County is the limestone of the Mokau River district, which is a continuation of that in Awakino County. According to Park, limestone about 60 ft. thick is exposed at water-level at or near Patokatoka Creek, four or five miles from the mouth of the Mokau River (two miles in a straight line), and is again seen at Mangatawa, seventeen or eighteen miles up the river (eight miles from the sea in a straight line), 200 ft. above the river.* The limestone hereabouts is of flaggy character, 40 ft. thick, and composed of Foraminifera and echinoderm remains (Park, 1887, p. 178). The following report, written by Dr J. Henderson early in 1917, apparently refers to almost the same locality:—

" *Limestone, Mokau River.*

" Many years ago a lime-kiln was built on the south bank of the Mokau River about nineteen miles from its mouth. Work ceased more than a dozen years ago, and kiln and quarry are now concealed by a dense growth of vegetation. As exposed in a small creek near the kiln, the limestone lies flatly and rests on soft sandstone. The top of the layer was not observed, but at least 40 ft. of massive yellowish limestone is exposed. A sample from this contained 96·6 per cent. of calcium carbonate and 1·83 per cent. of matter insoluble in acid, while a second sample, from a large loose block of harder and denser limestone, gave 95·0 per cent. of calcium carbonate and 3·27 per cent. of matter insoluble in acid. The thickness and extent of this deposit are unknown.

" The limestone occurs on the top of a steep ridge, about 800 ft. above the river, and transport to the kiln will not be difficult. The only means of approach, however, is by the river. Until two years ago small steamers carried coal to New Plymouth from a mine several miles up-stream from the kiln. Now it is possible to reach the limestone in a launch only at high water. At low water, owing to the presence of snags and the silting of the channel, the river is navigable for only seventeen miles."

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* The height is probably much greater.

The Mokau limestone is a hard yellowish-white stone, composed chiefly of the remains of Foraminifera (Amphistegina), calcareous algæ (Lithothamnium), Polyzoa, &c. The calcium-carbonate content is high, as is shown by the analyses below. Some of the analyses in the table on page 101 (Awakino County) probably also belong here.

	(1)	(2)	(3)
Matter insoluble in acid, or silica ..	0·85	0·74	1·93
Alumina	0·25	0·21	2·49
Iron oxides	0·24	0·22	
Calcium carbonate	95·92	96·20	89·52*
Magnesium carbonate..	2·63	2·49	2·50*
Water, &c.	0·11	0·14	1·95
Alkalies	..	..	0·64
Lime not accounted for as carbonate ..	..	..	1·31*
	100·00	100·00	100·34
Quicklime in calcined stone (per cent.) ..	95·4	95·8	87·4 (or 88·7)

References.—(1) (2) Highly crystalline limestones, "forwarded by the Hon. the Minister of Mines (Mr. James McGowan) from Waitara." Col. Lab. 33rd Ann. Rep., 1900, p. 11. Lab. Nos. 8473/1, 2. "Both are very pure, and fit for lime-making and building purposes." The locality of these samples is uncertain. They are here assigned to Mokau River as the nearest likely locality.

(3) Shelly limestone from near old lime-kiln, Mokau River, forwarded by Mr. Charles N. Taylor to the Geological Survey early in 1914. Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab. No. E 117.

Between six and seven miles in a direct line from the sea limestone occurs in the valley of the Mohakatino River, and thence inland forms thick beds, through which the Mohakatino and its tributary, the Waipapa, have cut deep narrow gorges for miles. The limestone in places is 100 ft. thick, and is in general of excellent quality, but access to every part of the deposit is difficult.

In the southern part of Clifton County bands of shelly limestone, which are usually very arenaceous, and generally pebbly, occur. Wherever accessible they have been quarried in order to obtain roadmaking material. Mr. H. H. Sharp, in his report mentioned on page 100, describes a deposit in the Purangi district close to Mangaoapa Road, near the Waitara River, and four miles north from Kiore Railway-station, or less than three miles as the crow flies. The present face is about 20 ft. high (1916). The stripping is considerable, and will increase as the face is carried into the hill. The stone is harder than that from Waiwiri Road (Stratford County, see p. 122), and contains flinty seams (probably highly arenaceous bands). The sample forwarded by Mr. Sharp is a hard, harsh-textured, bluish-grey, arenaceous rock consisting of shell casts filled with calcareous and sandy matter rather than shells. A part was analysed, with the following result:—

Silica	24·66
Alumina and iron oxides	5·74
Lime	36·99
Magnesia	1·12
Phosphoric anhydride	0·13
Carbonic anhydride, moisture, and organic matter	29·73
Alkalies and undetermined	1·63
	100·00

The lime is equivalent to 66·05 per cent. of calcium carbonate, but probably the true percentage of calcium carbonate is little, if any, over 60 per cent.

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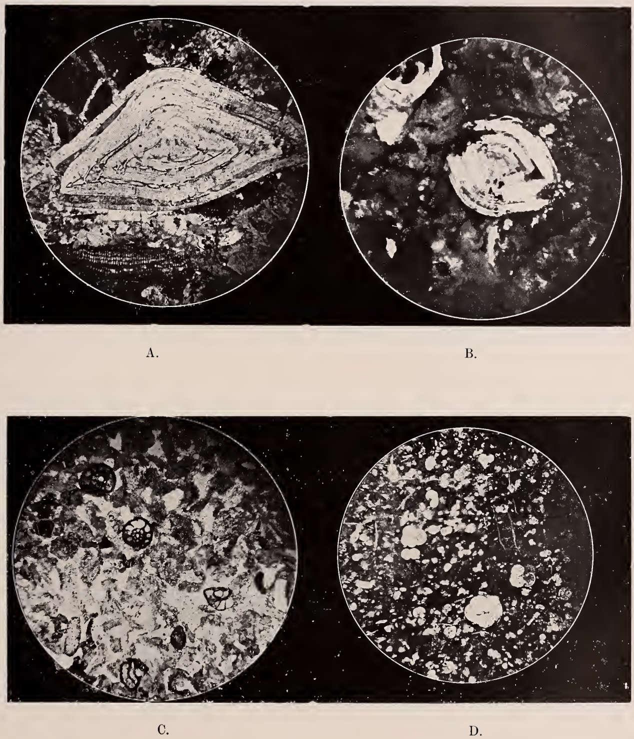
* Calculated from—Lime (CaO), 51·44 per cent.; magnesia (MgO), 1·19 per cent.; carbonic anhyride (CO_2), 40·70 per cent.

PLATE VI.



A. Limestone, Mokau. Large *Amphistegina* with *Lithothamnium* below. Magnified 20 diameters.
B. Limestone, Horahora (Whangarei County), with a nearly round *Amphistegina*. Magnified 20 diameters.
C. Foraminiferal Limestone, Milburn (Bruce County), with *Rotalia*, &c. Magnified 20 diameters.
D. Hydraulic Limestone, Kaiwaka (Otamatea County), with *Globigerina*. Magnified.

[From a paper by P. Marshall in vol. 48, Trans. N.Z. Inst.]

Reference.—Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. 1454/2. (Locality described only as in Ngatimaru Survey District.)

Park mentions that the pebbly shell-beds seen on the coast at Onairo and Urenui are well developed inland in the valleys of the Makara and Taramokau (Taramoukou) streams, and on the ridge at the source of the Makatui (1887 report, p. 179). The position of the last locality is uncertain. He also speaks of hard argillaceous limestone bands at Onairo, and of numerous concretionary nodules in thin-bedded clays at Whitecliffs (1887 report, p. 65).

Summary of Limestone Resources and of Means of Transport.

The best source of lime for Clifton County appears to be the limestone on both banks of the Mokau River. That at Patokatoka is near navigable water, but the amount of high-grade or even moderate-grade rock is small. If limestone from Mokau is not available, lime could be imported from Awakino, Kawhia, or Golden Bay. The county has the ports of Waitara and Mokau (at present accessible only for small vessels) on its southern and northern boundaries respectively. The Tongaporutu River can also be entered by small vessels. A short branch railway from the New Plymouth – Wellington line reaches Waitara. The Stratford–Okahukura line, now in course of construction, passes near its eastern boundary, and at one point (Tangarakau district) will enter the county for a mile or two. At present the county roads are woefully incomplete, but in a few years time will probably be much improved and extended.

Literature.

Portions of the southern part of Clifton County have been surveyed in detail, and the results are embodied in N.Z. Geol. Surv. Bull. No. 14, 1912, and in a bulletin now being compiled. In addition, a geological survey of the Mohakatino and Mokau districts has lately been completed.

The chief references to the geology of the county will be found in the following publications :—

Rep. of Geol. Explor., No. 4, 1867, pp. 2–4; No. 12, 1879, pp. 20–22; No. 18, 1887, parts of pp. xl–xlii, 42–47, 60, 65, 68, 73, 177, 178, &c.

Bell, J. M.: "Preliminary Report on the Taranaki Oilfield." Parl. Paper C.–14, 1909.

4th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1910, pp. 5–9, 19.

N.Z. Geol. Surv. Bull. No. 14, "The Geology of the New Plymouth Subdivision," 1910.

Rep. of Native Affairs Committee, Mokau-Mohakatino Block, Parl. Paper I.–3A, 1911. On pp. 33, 69, 75, 153, 225, 226, &c., are references to limestone.

Trans. N.Z. Inst., vol. 48, 1916, p. 93 (Marshall). Brief reference to Mokau limestone.

Other references to geological literature will be found in N.Z. Geol. Surv. Bull. No. 14, and in the forthcoming bulletins on the Egmont and Mokau subdivisions.

37. OHURA COUNTY.

Roughly, the geology of Ohura County is similar to that of the northern part of Clifton County. Tertiary coal-measures are well developed in the western part of the county, whilst in the north-eastern part rhyolitic tuff is the prevailing rock, and covers the Tertiary sedimentaries almost entirely. Calcareous claystone, however, appears in the Ongarue Valley, and there is an unconfirmed report of some limestone in that district, but this is probably a mistake. Flaggy shelly limestone is found near Totoro, on the Mokau River, in or near the north-west corner of the county (Park, 1887 report, p. 46). The calcareous claystones (commonly called "papa") of the Wanganui River may contain calcareous concretions and some bands of rock approaching limestone. Tertiary limestone is in fact mentioned by J. C. Crawford as occurring above Paparoa (Trans. N.Z. Inst., vol. 2, 1870, p. 357).

What is known of the geology of Ohura County suggests that a limestone stratum lies buried beneath the surface, and if not hidden by unconformably younger rocks, such as the rhyolite tuff, may possibly outcrop east of the belt of coal-measures.

No analysis of limestone from Ohura County has been found in the literature consulted.

Summary of Limestone Resources and of Means of Transport.

Apparently Ohura County will have to depend mainly upon outside sources for much of its carbonate of lime. The Main Trunk Railway from Waimiha to Taumarunui runs along or near its eastern boundary, and the Stratford–Okahukura Railway when completed will intersect the heart of the county. A line up the Waitewhena Valley, from Ohura into Waitomo County and on to Puketutu or Te Kuiti, is also proposed. Ultimately there will be good facilities for the introduction of Waitomo County limestone into nearly all parts of Ohura County. At present many of the roads are poor or only partly made.

Literature.

The chief references to the geology of Ohura County are in the following publications:—

Rep. of Geol. Explor., No. 18, 1887, parts of pp. xl-xlii, 65, 66 (Paparoa), 72, 73, 172–74, 180, 181, 182.

Trans. N.Z. Inst., vol. 1, 2nd ed., 1875, p. 315 (Crawford); vol. 2, 1870, p. 357, &c. (Crawford); vol. 20, 1888, part of pp. 316–32 (Cussen).

Crawford, J. C., in *Wellington Provincial Gazette*, February, 1862, pp. 12, 19, &c. This publication has not been seen by the writers.

38. KAITIEKE COUNTY.

In the western part of Kaitieke County the Wanganui River and its tributaries expose calcareous claystones ("papa") and sandstones. In the Retaruke Valley there are seams of brown coal, rather thin and dirty. The eastern part of the county is volcanic. Here, on or close to the county boundary, are the apparently extinct volcanoes of Ruapehu and Tongariro, and the active volcano Ngauruhoe. The prevailing rock of these mountains is andesite. On the lower country rhyolitic tuff is present in places. The Tertiary claystones of the county contain calcareous concretions and thin bands of limestone, but the thick tabular limestone so well seen in Kawhia, Awakino, and Waitomo counties is apparently absent. Cussen states that clay marl or "blue papa rock" can be traced to a height of 2,100 ft. on the Hunua Range, twelve miles south of Taumarunui. The beds dip to the south or south-west at angles varying from 3° to 15°. In the Otaunui Valley Cussen observed "large partly rounded boulders of tufaceous sandstone or possibly septaria" (concretions) in the marls. Impure limestone occurs in the Retaruke watershed (Bell, J. M., 1910 report).

Summary of Limestone Resources and of Means of Transport.

Kaitieke County has little limestone, and must evidently depend chiefly on Waitomo County for its supplies of lime. The Main Trunk Railway passes through the heart of the county, and forms a good base from which supplies can be distributed. From Te Kuiti to Raurimu, in the central part of the county, is sixty-three miles; to Waimarino,* towards the south of the county, is another seven miles; and to Pokako, on or near the border of the county, nine miles more: or in all seventy-nine miles from Te Kuiti. As yet there are few roads in the county. The Wanganui River is on its western boundary, and is navigable for small steamers, but cannot be considered a feasible route for the transport of heavy goods.

Literature.

The chief references to the geology of Kaitieke County are contained in the following publications:—

Trans. N.Z. Inst., vol. 1, 2nd ed., 1875, pp. 323, 324, &c. (Crawford); vol. 2, 1870, pp. 355, 357 (Crawford); vol. 20, 1888, part of pp. 316–32 (Cussen).

Rep. Geol. Explor., No. 18, 1887, parts of pp. xl-xlii, pp. 59, 65 (Puketapu), 70, 71, 171, 172, 173, 180, 181, &c. See also references to the upper Wanganui River.

4th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.-9, 1910, pp. 9–14 (J. M. Bell, on Retaruke coal).

39. TARANAKI COUNTY.

The geology of Taranaki County is simple. In the west and south-west are the volcanic Kaitake and Pouakai ranges, together with the northern slope of Mount Egmont, a beautiful extinct volcano, reaching a height of 8,260 ft. The rest of the county is covered with a coat of andesitic volcanic débris, thick near the mountains, but in the east of the county, at fourteen miles and more from the summit of Mount Egmont, so thin that an underlying series of young Tertiary conglomerates, sandstones, claystones, and impure shelly limestones known as the "Onairo Series" (see also Clifton County) is exposed where streams have cut away the volcanic material. There are in parts of the county somewhat numerous minor points of eruption, usually marked by small so-called "conical" hills. These are seen near Inglewood, near Lepperton, and on the western boundary of the county, west of Okato.

The shelly limestones of the Onairo Series are unfortunately very poorly developed in Taranaki County, and nothing that could be called limestone was observed in the county during the course of the geological surveys undertaken of late years. Between Kaimata and the Waitara River, and no doubt elsewhere, calcareous concretions are common in the blue claystones. About 20 chains north-east of the mouth of Tapuae Creek is a small patch or disconnected block of fine-grained calcareous sandstone with fossils. This is called "limestone" by E. de C. Clarke, but is far too impure to deserve that name.

Taranaki County possesses at least two small deposits of calcareous sinter or travertine. One of them—the larger—is near German Hill, a dome-like elevation five miles west-south-west of Inglewood; and the other is three miles south-south-west of the same town, on the left bank of a branch of the Waiongona-iti Stream, at a point rather more than 22 chains west of the junction of Dudley and Bedford roads. Neither deposit is large enough to be of any value except for local use. The travertine can be easily quarried and broken into small lumps for spreading on the land. On later pages similar deposits east of Rahotu and near Opunake will be mentioned. A sample of calcareous sinter obtained near German Hill in 1915 was analysed, with the following results:—

---

* Waimarino Railway-station is not in Waimarino County, but in Kaitieke.

Silica	0·70
Alumina and iron oxides	0·86
Lime	52·92
Magnesia	1·24
Phosphoric anhydride	0·16
Carbonic anhydride	42·44
Water and organic matter	1·46
Alkalies and undetermined	0·22
	100·00

Reference.—Analysis made in Dom. Lab., 1915. Lab. No. F 469. Results not published in annual report. The carbonate of lime is at least 93·4 per cent., or, reckoned on the dry sample, nearly 95 per cent.

The following two analyses of shelly limestone are ascribed to New Plymouth, but probably do not even belong to Taranaki County as now constituted:—

	(1)	(2)
Matter insoluble in acid	13·40	31·92
Calcium carbonate	85 to 86	68·08

References.—(1) Shelly limestone from "New Plymouth," forwarded by Mr. H. H. Brown. Col. Mus. and Lab. 12th Ann. Rep., 1878, pp. 26, 52. Lab. No. 1865.

(2) "Shell-deposit" from "New Plymouth." Col. Mus. and Lab. 27th Ann. Rep., 1893, pp. 22–23. Lab. No. 5984. Perhaps forwarded by the Minister of Lands (?).

The calcareous concretions of the Taranaki District may be represented by a sample forwarded in 1875 or thereabouts to the Colonial Laboratory by Mr. Decimus Atkinson. Its analysis is as follows:—

Siliceous matter, sand, and clay	29·34
Soluble silica	1·99
Carbonate of iron, with a little oxide of iron	15·24
Alumina	0·92
Calcium carbonate	36·68
Magnesium carbonate	15·53
Alkalies, soluble in acid used	0·30
	100·00

Reference.—Col. Mus. and Lab. 11th Ann. Rep., 1876, p. 15. Lab. No. possibly 1796 (not definitely stated). "This is a somewhat hard bluish-grey-coloured stone, fossiliferous, and in its structure apparently concretionary, while the analytical results given above show it to be of a dolomitic character."

Means of Transport, &c.

Taranaki County will have to obtain the greater part of its lime from outside sources. At present the most available deposits are those of the lower Mokau River, Kawhia Harbour, and Golden Bay, Nelson. The completion of the railway from Stratford to Okahukura will enable lime to be imported from Waitomo County, but the railway haulage from, say, Te Kuiti will be well over a hundred miles. The county has good means of communication. Medium-sized vessels can berth at the New Plymouth Breakwater, and on the north-east boundary is the small port of Waitara, with a roadstead anchorage for large vessels. A railway runs southward from New Plymouth to Wellington, with a short branch from Lepperton to Waitara. A line from New Plymouth to the south-west, which will ultimately pass round the Cape Egmont Peninsula, is projected, and will probably be constructed in a few years. The county, thanks to the abundant supply of roadmaking material furnished by the volcanic rocks, has roads that either are excellent or can easily be made so.

Literature.

The whole of Taranaki County has been geologically surveyed in detail. The results are embodied in Geol. Surv. Bull. No. 14, "The Geology of the New Plymouth Subdivision," 1912, by E. de C. Clarke, and in a bulletin not yet published, "The Geology of the Egmont Subdivision." In addition to the literature cited by Clarke the following reports may be mentioned :—

> 8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914, pp. 136–42. (2nd ed., 1915.) 9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, pp. 76, 80–81. 10th Ann Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, pp. 2, 4–7.

40. STRATFORD COUNTY.

In general the geology of Stratford County is similar to that of Taranaki County, but since it stretches many miles farther to the east sedimentary rocks of Tertiary age are much better exposed, and at an average distance of eighteen miles or a little less from the summit of Mount Egmont volcanic débris practically disappears. The eastern part of the county is geologically unexplored. The shelly calcareous bands or impure limestones of the Onairo Series are fairly well developed in the eastern part of the county at points over fifteen miles from Mount Egmont, but are never so situated as to be able to yield large amounts of rock by mere quarrying. In nearly all cases the calcareous bands disappear under a thick cover of other rocks, and consequently when the outcrops are exhausted will either have to be won by underground mining or abandoned. Many of the known outcrops have been worked in order to obtain material for roadmaking, the eastern part of Stratford County being very badly supplied with suitable roadmaking material, in sharp contradistinction to the western part near Mount Egmont. The following localities where calcareous sandstone, shelly limestone, or conglomerate occur may be mentioned :—

(1.) A short distance (about 30 chains) north-west of Popuanui trig. station, and near Taihore Road, south of Strathmore, shelly conglomerate outcrops somewhat prominently. This locality is near Whangamomona County boundary, and possibly is in that county.

(2.) About two miles and a half north of Douglas, and half a mile or less east of the railway and road, there are two small quarries in a nearly horizontal bed of shelly limestone about 8 ft. thick. The limestone is overlain and underlain by fine-grained fossiliferous argillaceous sandstone, which weathers brown, but where unweathered is blue in colour. In places it is very sandy and pebbly, the pebbles reaching a diameter of about 1 in. The quality is therefore very variable, but, on the whole, poor, and this is shown by the following analyses :—

	(1)	(2)	(3)
Matter insoluble in acid	26·34	20·79	11·70
Calcium carbonate	67·27	73·10	82·91
Phosphoric anhydride	0·09	..	..

Reference.—Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. Nos. G 244/1–3. Samples collected by P. G. Morgan in March, 1916. (1) Average sample from upper quarry; (2) average sample from lower quarry; (3) picked sample from lower quarry.

The limestone has been worked for roadmaking, and appears fairly suitable for that purpose. The quantity that can be quarried by openwork is, however, not large. A great amount of stone could no doubt be obtained by underground mining, but probably the expense of such a system would prevent its adoption. A dray-track leads from the main road to the quarries, which when visited in March, 1916, had not been worked for some time. The height above the neighbouring main road is about 80 ft., and above sea-level 780 ft.

(3.) Less than half a mile to the north-north-west of the outcrops described above a band composed very largely of fossil oysters is exposed in a railway-cutting. It lies nearly horizontal, is several feet thick, and may possibly be correlated with the shell limestone at the quarries east of the railway.

(4.) Two miles and a quarter north of Huiroa Post-office shell rock of no great thickness outcrops on or near Douglas Road.

(5.) A mile south-west of Mr. Gwatkin's house, near Huiroa oil-bore, and half a mile south of the creamery on Makuri Road, a band of shelly rock has been quarried for roadmaking.

(6.) A full mile to the south-west of the last-mentioned outcrop, shell rock outcrops a short distance west of Waiwiri Road. Half a mile to the south, but a few chains to the east of the road, more shell rock outcrops at a point 670 ft. above sea-level. Twenty-five chains or more to the south, in the valley of a small branch of Waiwiri Stream, shelly limestone of considerable thickness (20 ft.) overlain by sandstone has been quarried, and years ago was burnt in a lime-kiln erected on the spot. At the time this outcrop was visited (October, 1915) some of the rock had been pulverized for agricultural use. The limestone appeared to be somewhat impure, and consisted largely of shell casts filled with and cemented by calcareous matter. It was light-coloured, and very harsh to the touch. A sample obtained from this quarry in 1916 by Mr. H. H. Sharp, Public Works Engineer, was analysed, with the following results:—

Silica	8·19
Alumina and iron oxides	1·22
Lime	50·12
Magnesia	0·59
Phosphoric anhydride	0·11
Carbonic anhydride, moisture, and organic matter	39·45
Alkalies and undetermined	0·32
	100·00

The lime present is equivalent to 89·50 per cent. of calcium carbonate.

Reference.—Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. 1454/1.

Mr. Sharp reports that the sample (No. 14 of his list) came from a deposit near Waiwiri Road, about four miles from Toko Railway-station. This had already been worked on a small scale, and the rock found to contain 85 per cent. of calcium carbonate. Burning and crushing had been discontinued owing to want of capital. Outcrops of limestone up to 20 ft. thick were to be seen for about 30 chains, but the stripping after going into the hill for 20 ft. or 30 ft. would be heavy. The locality was easily accessible, and there was a nearly level road to the railway.

(7.) Two miles or more west of the Waiwiri Road kiln outcrop, shell rock is exposed in a tramway-tunnel at the head of Ahuroa Stream. Two miles or less to the north and about 30 chains east of the creamery on Stanley Road shell rock again outcrops. More shell rock is seen on the banks of Ahuroa Stream, three-quarters of a mile to the north. In this part of Stratford County a good deal of volcanic débris overlies the Tertiary rocks, and in places masks their outcrops.

(8.) About 55 chains north-east of Gordon Railway-station, and perhaps 15 chains north of Ohura (East) Road, a bed of shelly limestone 8 ft. thick has been quarried in order to obtain roadmaking material. "The quarrying has been carelessly done, the stripping from the top being thrown on the limestone underfoot; but in any case as work proceeds the overburden must increase in thickness, and the position of the stone is not suitable for quarrying." (Ongley, 1917 report, p. 5.) Two miles west of this, north of Ahuroa Road, and rather over a quarter of a mile west of Waiwiri Road, there are three small quarries in pebbly shell limestone 20 ft. thick. The stone, which is probably a continuation of that at the kiln some distance to the north (No. 6), contains many pebbles of greywacke. In the intervening country, some distance to the south-east, shell rock 15 ft. thick outcrops on Ahuroa Road near its junction with Waiwiri Road. Concerning these occurrences Mr. Ongley writes: "Near Waiwiri Road, and alongside Ahuroa Road near its junction with Waiwiri Road, four quarries have been opened, and the stone is 15 ft. to 20 ft. thick, and of better quality [than near Gordon]; but it is patchy, and in places about one-third its bulk consists of greywacke pebbles. Here also careless work in the past has made present work difficult. The quarries have been opened in the outcropping edges of the bed, the overburden is thick, and it is not known how much shell rock occurs. Probably more outcrops will be found, but owing to the bad position of the stone no large quarries can be worked." (1917 report, p. 5.)

(9.) On the east bank of the Patea River, four miles south-east of Toko, shell rock again appears.

The following five analyses are all attributed to Stratford or Stratford district, except No. 4, which is said to come from Midhirst. No calcareous rock is known to outcrop within several miles of either of these towns, and the samples analysed may be assumed to have come from the country to the east.

	(1)	(2)	(3)	(4)	(5)
Matter insoluble in acid	30·21	6·17	..	12·8	..
Alumina	1·48	..	..	2·3	..
Iron oxides		0·96	..	1·5	..
Calcium carbonate	65·33	89·75	86·76	79·1	78·40
Magnesium carbonate	2·98	2·78	..	0·8	..
Water	..	0·21	..	3·5	..
Organic matter	..	0·13	..		
	100·00	100·00	..	100·0	..

References.—(1) Fossiliferous limestone from Stratford, forwarded by Mr. H. J. Gaby. Col. Mus. and Lab. 26th Ann. Rep., 1892, p. 28. Lab. No. 5687.

(2) Tough, coherent, light-fawn-coloured, shelly limestone from Stratford, forwarded by Mr. E. M. Smith, M.H.R. Col. Lab. 28th Ann. Rep., 1894, pp. 13, 43. Lab. No. 6264. No alumina recorded in analysis. "An excellent limestone" that "would make a good lime when burned." It is much to be regretted that no such limestone occurs in quantity in the Stratford district, but hand samples of similar quality can be selected at Waiwiri Road and other places.

(3) Shelly limestone from Stratford, forwarded by W. J. Lewis. Col. Lab. 31st Ann. Rep., 1898, p. 11. Lab. No. 7705. "Would burn into good lime." Other samples forwarded by Mr. Lewis contained only 43 per cent. of calcium carbonate.

(4) From Midhirst, forwarded by J. W. Mackay. Col. Lab. 37th Ann. Rep., 1904, p. 9. Lab. No. 9561.

(5) Forwarded by Toko Lime Company (probably from Waiwiri Road). Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab. No. E 837.

The following analysis of a sample from the Stratford district, forwarded by the Mines Department to the Dominion Laboratory in 1915, deserves separate statement:—

Silica (sand, &c.)	7·45
Alumina and iron oxides	0·88
Lime	50·28
Magnesia	0·25
Carbonic anhydride	39·40
Moisture and organic matter	1·26
Phosphoric anhydride	0·22
	99·74
Quicklime in calcined stone (per cent.)	85·2

Reference.—Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. No. F 784. The carbonate of lime is not less than 88 per cent.

The following nearly complete analysis of a limestone said to be from New Plymouth, forwarded to the Colonial Laboratory in 1902 by Mr. E. M. Smith, M.H.R., is here attributed on circumstantial evidence to the district east of Midhirst and Stratford:—

Water lost at 100° C.	0·65
Carbonic anhydride and organic matter	33·30
Silica (SiO_2)	20·10
Alumina (Al_2O_3)	2·00
Iron sesquioxide (Fe_2O_3)	1·00
Titanium oxide	0·04
Lime (CaO)	41·75
Magnesia (MgO)	0·90
Phosphoric anhydride (P_2O_5)	0·09*
Sulphuric anhydride (SO_3)	0·17†
	100·00
* Equivalent to phosphorus	0·04
† Equivalent to sulphur	0·068

Reference.—Dom. Lab. 36th Ann. Rep., 1903, p. 8. Lab. No. 9326. On page 9 are analyses of " blue clay found near limestone, Midhirst," and " yellow clay found in vicinity of limestone, Midhirst," also forwarded by Mr. E. M. Smith. Whatever the source of the limestone, the high percentage of silica renders it of little value as a flux for iron-ores, the object in view when it was analysed.

Calcareous concretions are abundant in the claystones of Stratford County. They are especially abundant in the north-eastern part of Ngatimaru Survey District, much of which, however, is in Clifton County.

Nothing definite is known about the limestone that may exist in the extreme east of Stratford County, where it abuts on Patea and Waitotara counties. That part of the county is hilly, semi-mountainous country, rising to heights of over 2,000 ft.

Summary of Limestone Resources and of Means of Transport.

In the Toko, Douglas, and Huiroa districts the somewhat thin and decidedly impure shelly limestones will be of some value if pulverized and used as soil-dressings. Any attempt to burn them, however, is doomed to financial failure. The settled portions of the county have good communications. The Wellington - New Plymouth Railway crosses the most thickly populated part of the county in a north-and-south direction. A short branch line has been made westward from Waipuku to open up stone-quarries on the slopes of Mount Egmont. The railway from Stratford to Okahukura, on the Main Trunk line, has been constructed far beyond the county boundary, and when completed will enable lime to be imported from the Te Kuiti district. The railway haulage, however, even to the border of the county, will probably be over a hundred miles.

Near Stratford and to the west of that town the roads are excellent, material for their construction being plentiful, but in the Huiroa district, &c., the want of suitable macadamizing material is shown by the absence of good roads.

Literature.

The western two-thirds of Stratford County have been surveyed in detail, and the results will be embodied in the forthcoming Egmont Bulletin, mentioned on a former page. Until this bulletin appears the following publications may be consulted:—

Rep. Geol. Explor., No. 18, 1887, parts of pp. xl–xlii, 29, 30, 59, 71, 72, 73, 179, &c., and map opposite p. 32. A paragraph on p. 179 applies to the extreme eastern part of the county. Pebbly shell-beds are mentioned.

Mines Rep., Parl. Paper C.-9, 1899, pp. 28–29. The shell limestones between Toko and Strathmore are described.

9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.-2, 1915, pp. 76, 78–81.

10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.-2B, 1916, pp. 2, 4–7.

41. Whangamomona County.

The chief rocks of Whangamomona County are Miocene and Pliocene claystones, sandstones, conglomerates, and limestones. Towards the north-east, in the Wanganui Valley, there may be pumiceous tuffs, while in the north brown coal similar to that of the Mokau district appears in the Tangarakau Valley. It is not known whether the Kawhia limestone horizon is represented or not. The southern part has been geologically explored, and there the rocks are very similar to those of the adjoining part of Stratford County. There is no known outcrop in this part of Whangamomona that can be called limestone. Moderately calcareous rocks are known to occur as follows:—

(1.) Calcareous sandstone outcrops on Akama Road between Huiroa and Huiakama. No other information about this occurrence is available.

(2.) Calcareous shelly sandstone or impure shelly limestone outcrops on or near the crest of Te Wera Ridge (*a*) half a mile to three-quarters of a mile, (*b*) a mile and a half, and (*c*) at Nolan's quarry over two miles east of north from Te Wera trig. station. At the last locality it may be described as a fairly thick somewhat irregular band of shelly limestone, overlain and underlain by sandstone. The rock here has been quarried for roadmaking, but is somewhat too friable to be satisfactory for that purpose. A considerable quantity of calcareous rock could be mined here, but the quality is too poor to justify its being recommended for agricultural uses. The analysis mentioned on pages 129–30 (No. 6800—shelly limestone with 70 per cent. carbonate of lime) may possibly represent material from Nolan's quarry.

(3.) Calcareous shelly sandstone outcrops on the roadside about two miles north-east of Te Wera Railway-station. This locality is about a mile and a quarter east-south-east of Nolan's quarry, and at a much lower elevation, being in the valley-bottom. The rock here seems very poor.

(4.) Near Strathmore, several miles south of Te Wera, there are shelly bands of various descriptions, but none is known to approach limestone. The shelly conglomerate near Popuanui trig. station mentioned on page 121 is farther south, and may be either in Whangamomona or Stratford County.

(5.) Shelly conglomerate and impure shelly limestone bands appear in the banks of the Wanganui River, which forms most of the eastern boundary of the county.

In the *Journal of Agriculture*, vol. 17, No. 2, Aug., 1918, B. C. Aston gives the following analyses of impure limestones from Whangamomona County: Te Wera, (1) 57, (2) 66, and (3) 66 per cent. of calcium carbonate. Kohuratahi, (1) 80, and (2) 77 per cent. of calcium carbonate.

Summary of Limestone Resources and of Means of Transport.

Whangamomona County appears to have little limestone, and must depend on outside sources for its main supply of lime. The completion of the Stratford–Okahukura Railway will bring it within a hundred miles by rail of the Waitomo County deposits near Te Kuiti, &c. The railway at the time of writing has reached, or almost reached, the northern boundary of the county, but otherwise means of communication are poor. The Wanganui River is probably of little value for the transport of heavy materials. In many parts of the county settlement is only just beginning, and roads are merely formed, or are represented by horse-tracks only.

Literature, &c.

The southern part of Whangamomona County has been geologically surveyed in detail, and will be described in the Egmont Bulletin. Other publications that refer to the geology of the county are—

Rep. of Geol. Explor., No. 18, 1887, parts of pp. xl–xlii, 72, 73, 172, 173, 174, 181, 182, and map opposite p. 32.

Parl. Paper C.–9, 1899, pp. 28–29 (bound in Mines Rep.).

9th and 10th Ann. Rep. N.Z. Geol. Surv., as cited under Stratford County.

42. WAIMARINO COUNTY.

The greater part of Waimarino County from the Wanganui River to the neighbourhood of the Main Trunk line is underlain by Miocene and Pliocene conglomerates, sandstones, claystones, and limestones, well seen in the cliffs that confine the Wanganui River to its course. In places these rocks are overlain by a veneer of volcanic débris, thickening towards the north-east. North-east of Ohakune volcanic rocks of andesitic type predominate, and form the main part of Mount Ruapehu, 9,175 ft. in height. There are local centres of eruption between the old township of Ohakune and Rangataua, marked by small lakes filling ancient craters.

By far the most prominent rock of the Tertiary series, as usual in the greater part of the North Island, is the claystone (" papa "), and this contains numerous calcareous concretions. Limestone is not at all abundant, and where it occurs is usually neither thick nor yet very pure. The following occurrences have been recorded in the reports consulted :—

(1.) The rocks crowning the high ranges near Pipiriki are brown micaceous sandstones underlain by a bed of hard pebbly limestone, which in turn is underlain by blue clays with concretions. (Park, 1887 report, p. 171.)

(2.) At the caves near Mangaio, a few miles above Pipiriki, blue clays are interbedded with layers of pebbly limestone. The caves are narrow water-channels in the blue clays, with a limestone roof. (Park, 1887 report, p. 172.)

(3.) At Utapu pebbly limestones are well exposed on the right bank of the Wanganui River (*i.e.*, in Waitotara County). (Park, 1887 report, p. 172.) Utapu is about half-way from Mangaio to the Tangarakau junction.

(4.) Below the junction of the Mangahani with the Manganui-a-te-ao River soft yellow micaceous sandstones are underlain by shelly limestone about 15 ft. thick. This limestone contains pebbles of slate and sandstone in such abundance that it might in most cases be called a shelly conglomerate. (Park, 1887 report, p. 171.)

Means of Transport, &c.

Waimarino County will probably have to obtain its lime from Waitomo County by means of the Main Trunk Railway, which traverses the county from a few miles south of Waimarino Railway-station (Kaitieke County) to Waiouru. The distance by rail from Te Kuiti to Ohakune Railway-station is ninety-nine miles, and to Waiouru is another seventeen miles. Thus the railway haulages approach or exceed a hundred miles. There is a branch line from Ohakune to Raetihi; and the Wanganui River is easily navigable for small steamers as far as Pipiriki, and perhaps farther.* Roads are as yet few, much of the country being unsettled.

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* Steam-boats specially built for the tourist traffic ascend the Wanganui as far as Taumarunui.

Literature.

The chief references to the geology of Waimarino County will be found in the following publications :—

Trans. N.Z. Inst., vol. 1, 2nd ed., 1875, pp. 322, 323 (Crawford) ; vol. 2, 1870, pp. 351–53, 357, 358, 359, &c. (Crawford).

Rep. of Geol. Explor., No. 18, 1887, parts of pp. xl–xlii, xlix, 1, 58, 65, 69–73, 155–56, 168–73, 180–82, and map opposite p. 32.

43. EGMONT COUNTY.

Practically the whole of Egmont County is covered by volcanic tuff and agglomerate or water-sorted material derived from those rocks. Andesitic lavas are seen on Mount Egmont and in a few of the innumerable conical hills that occur everywhere on the lowlands from Warea (near the northern boundary) to Opunake, and thence eastward to Awatunu (on the eastern boundary). The blown sands of the coast-line, the material covering river-flats, and some Late Pleistocene sandstone form the only rocks of any consequence that fall outside the term " volcanic " in its extended sense. No limestone is found in the county, with the exception of small deposits of calcareous sinter similar to those mentioned in the description of Taranaki County. These are known to occur in the following localities :—

(1.) Some miles east of Rahotu, at a spot half a mile south of Kahui Road and a mile east of its junction with Okahu (Carrington) Road, calcareous sinter occurs on the north bank of a stream. The material is of greyish-white colour, cellular, and fairly friable. It extends about 3 chains to the north of the stream. The extent along the bank has not been recorded.

(2.) A little calcareous sinter is being deposited on the coast-line at a point two miles north-west of Opunake, and a little beyond trig. station H. In this case the sinter is no doubt being formed by water that has previously percolated through the neighbouring sandhills, and there dissolved some calcareous matter.

(3.) About four miles north of Opunake several deposits of calcareous sinter occur near Wiremu Road (a continuation of Okahu Road). They are described by Mr. M. Ongley, Assistant Geologist, as follows :—

" In Opunake Survey District deposits of calcareous sinter occur near Wiremu Road, the largest known deposits being on the farms of Messrs. G. Looney and H. Bartle. At Looney's the swampy stream is surrounded by conical hills of volcanic material, and in many places where the water trickles through the low ground sinter has been deposited. Mr. Looney has quarried and burnt some of this, but as only a small quantity of stone is known the erection of a kiln is not justified. Where Mr. Looney piled the stone the grass has made a good growth over it, and there seems no necessity either for burning the sinter or for crushing it to fine powder. It is generally full of holes, and is easily penetrated by the roots of grass, &c. ; hence the sinter, if broken small and applied to the ground, will give good results. At present the expenditure necessary to set up a crushing plant is not justified. More outcrops will probably be found, but the sinter is a surface deposit, and no extensive body of it occurs.

" At Bartle's the stream flows through felled bush, and the seepage from the conical hills on the banks has formed a ledge of sinter overhanging the stream for 2 chains, and from the bottom of the ledge stalactites hang down. But this again is only surface sinter, and is very limited in amount. Probably more patches will be found, and in many places the conditions are suitable for its formation. It has been suggested that the sinter is derived from some bed of limestone in the vicinity, but thick deposits of volcanic material cover the whole district from Egmont to the coast. It has been shown* that the volcanic rock contains up to one-tenth its weight of lime (CaO), and it is not necessary to look farther for the source of the lime."

A sample of "limestone" forwarded in 1909 to the Dominion Laboratory by Mr. G. Looney probably came from his farm near Wiremu Road. It contained 92·32 per cent. of calcium carbonate. (Dom. Lab. 43rd Ann. Rep., 1910, p. 12. Lab. No. 64.)

B. C. Aston has recently published three analyses of limestone from the Opunake district. The percentages of calcium carbonate given are 92·6, 92, and 87·2 respectively (Jour. Agri., vol. 17, No. 2, Aug., 1918, p. 100). The "limestone," no doubt, is calcareous sinter, similar to that described above.

Means of Transport, &c.

At present Egmont County has poor facilities for importing lime. Only very small vessels can berth at the Opunake jetty, and there is no other port, though in fine weather landings can be made at many places along the coast. A branch railway is being made from Te Roti to Opunake, and at some future time will no doubt be continued round the coast to meet a line from New Plymouth. This will enable lime to be obtained from Waitomo County, but the length of haulage will be considerably over a hundred miles. There is a possibility of obtaining lime from the Nukumaru and Waitotara districts, which are much nearer than Waitomo County. (See p. 131.)

The importation of lime by sea from Mokau River, Kawhia, or Golden Bay may ultimately be found more economical, especially if the port of Opunake can be improved. On the whole, the roads of the county are good, or can be made so with the aid of the excellent roadmaking material obtainable from the conical hills.

Literature.

The whole of Egmont County has lately been geologically surveyed, and the results will be published in the Egmont Bulletin. References to the geology of the county in the literature consulted are confined almost entirely to Mount Egmont and to casual mention of the coast-line. The following may be cited :—

Dieffenbach, Ernest: "Travels in New Zealand," vol. 1, 1843. On p. 139, in a chapter on Mount Egmont, casual mention of the country from Cape Egmont to Waimate is made.

10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, part of pp. 2, 4–7.

11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1917, pp. 5–6.

44. ELTHAM COUNTY.

The geology of Eltham County is similar to that of Stratford County, which adjoins it on the north. In the western part of the county are a few conical hills, near Egmont County boundary. Shelly rock or very impure limestone occurs on the banks of the Patea River four miles south-east of Toko, and again at a point four miles to the south and seven or eight miles east of Eltham. No doubt similar or better rock occurs here and there in the country to the eastward, but this district has not been geologically explored.

It is probable that Eltham County will have to obtain the bulk of its lime requirements from other parts of New Zealand. The eastern part of the county may be able to obtain sufficient lime for its soils from the bands of shell rock or shelly limestone mentioned above, by using calcareous claystone (so-called "papa") as a soil-dressing. The limestone near Nukumaru in Waitotara County may possibly be utilized for supplying lime to Eltham and other Taranaki counties, but otherwise lime will have to come by rail from the distant Te Kuiti district, or by sea from Mokau, Kawhia, or Golden Bay, to the ports of Patea, Opunake, or New Plymouth, and thence be railed to its destination. The settled parts of the county are fairly well roaded, so that internal communications are good.

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* N.Z. Geol. Surv. Bull. No. 14 (New Series), p. 23.

Literature.

Part of Eltham County has lately been geologically surveyed, and the results will be found in the forthcoming Egmont Bulletin. The following references to its geology found in the scanty literature may be cited:—

Rep. of Geol. Explor., No. 18, 1887, map opposite p. 32, and pp. 59 ("Drift Formation"), 60.

11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1917, pp. 5–6.

45. WAIMATE WEST COUNTY.

The geology and main surface features of the small county of Waimate West is similar to that of Egmont. The county, however, does not extend to Mount Egmont, and no minor centres of eruption in the form of conical hills have been mapped within its boundaries. Raised beaches, consisting of sand and pebbles capped by Pleistocene volcanic débris, become prominent on and near the coast south of Manaia. In this locality the cliff sections show 50 ft. or more of sandstone, with shelly layers, which are probably of Pliocene age. No limestone of any kind is known to occur in the county. The remarks *re* importation of lime under the heading of "Eltham County" apply to Waimate County also. The county has good roads, and the Te Roti - Opunake Railway now in course of construction runs through its northern portion.

Literature.

Waimate County has lately been geologically surveyed, and the results of the survey will appear in the Egmont Bulletin. Brief reference to its geology is made in 11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, pp. 5–6.

46. HAWERA COUNTY.

A set of Pliocene rocks, consisting of claystones and fine sandstones with occasional pebble-beds, is well developed in Hawera County. Outcrops of these rocks may be seen along the sea-cliffs and a few miles inland. The extreme eastern part of the county is not well known, but its geology is no doubt similar to that of the adjoining part of Eltham County. Thin pebbly limestones may therefore be expected to occur. Raised beaches are well seen along the coast-line, and inland for many miles. The surface coating of the western part of the county consists in part of water-sorted volcanic material, and in part of material derived from the Pliocene rocks. One or two small conical hills denoting centres of eruption occur between Hawera and the coast.

One sample of limestone supposed to be from Hawera County has been analysed in the Colonial (Dominion) Laboratory. It was forwarded in 1894 or 1895 by Mr. R. A. Nolan, of Hawera, and was stated to come from the top of a hill twenty miles inland. It is described as a shelly limestone, with about 30 per cent. of sand

and 70 per cent. of carbonate of lime (Col. Lab. 29th Ann. Rep., 1895, p. 12. Lab. No. 6800). It is possible, as mentioned on page 125, that this sample came from Nolan's quarry, Te Wera district, Stratford County. Recently B. C. Aston (*loc. cit.*, p. 99) has published part analyses of six limestone samples from "Hawera."

Hawera County will have to obtain most of its lime from outside sources. The nearest workable limestone deposits are in the Waitotara and Nukumaru districts. If these cannot be made use of, then lime may have to be imported by sea to the port of Patea (Patea County), and thence distributed through Hawera County by rail and road. The more settled part of the county is traversed by the New Plymouth – Wellington Railway, and is well roaded.

Literature.

Among the few obtainable references to the geology of Hawera County may be cited the following :—

Rep. of Geol. Explor., No. 18, 1887, pp. 59, 60, and map opposite p. 32.

Trans. N.Z. Inst., vol. 5, 1873, pp. 95 (moa-bones, mouth of Waingongoro, W. B. D. Mantell), 97–101 (first discovery of moa-bones, Richard Taylor); vol. 49, 1917, pp. 414–17 (Thomson, J. A., on "The Hawera Series").

47. PATEA COUNTY.

The principal rocks of Patea County are Middle and Late Tertiary conglomerates, sandstones, claystones, and limestones. In the coastal region these are unconformably covered by Pleistocene sands, clays, and gravels, which appear on a set of raised beaches, as in Hawera County. The latest rocks of the county are the blown sands of the coast-line and the alluvial deposits of the river-flats. Not much is known about the limestones of Patea County; but outside the county, on the south side of the Waitotara River near its mouth, a bed of polyzoan limestone 50 ft. thick is exposed. A little farther to the south-east are extensive outcrops of what Park calls the Nukumaru limestone, which is 250 ft. thick (see Waitotara County). Park states that this limestone "slowly rises inland, occupying the tops of all the higher bush-clad ranges towards the sources of the Kai-iwi, Waitotara, Whenuakura, and Patea rivers"— that is, it is found in all the inland part of Patea and adjoining counties (1887 report, p. 55).

Near Waverley (or inland of Waverley) the claystones appear to be highly calcareous, and there may also be some shell limestone, as is indicated by the following records of analyses :—

"No. 3298, two samples of marl from Waverley, per Mr. J. S. Thompson. No. 1 contains 67·4 per cent., and No. 2, 66·6 per cent. of carbonate of lime. These are very good marls. No. 3369, from the same person and place, is an inferior shell limestone.

" *Analysis.*

"Carbonate of lime	60·27
Carbonate of magnesia	2·47
Iron (oxides) and alumina	1·24
Siliceous matters (sand)	35·60
Water	0·42
Phosphoric acid	Trace
	100·00."

Reference.—Col. Mus. and Lab. 18th Ann. Rep., 1883, p. 44.

Summary of Limestone Resources and of Means of Transport.

How far Patea County can rely on its own lime deposits or those of the adjoining Nukumaru district is uncertain. A geological survey might possibly lead to the discovery of deposits having some value. The coastal region, with a railway, the port of Patea, and excellent roads, has good communications. The inland region is apparently almost unsettled and unroaded, the only township shown on the small-scale (10-miles-to-the-inch) county maps being Matapouri.

Literature.

There are few references to the geology of Patea County. The principal are—

Rep. of Geol. Explor., No. 18, 1887, pp. 29, 33, 55–60, 64–67, 169, 179 (source of Waitotara), and map opposite p. 32.

9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, pp. 103–4.

Trans. N.Z. Inst., vol. 49, 1917, part of pp. 414–17 (Thomson).

48. WAITOTARA COUNTY.

Much the same terms may be used in describing the geology of Waitotara County (an offshoot of Wanganui County) as of Patea County, but somewhat fuller information is available, partly owing to the navigable Wanganui River forming its eastern boundary. On and near the coast-line at Nukumaru what seems to be a very important limestone, according to Park, covers an area estimated at ten square miles, with a sea-frontage of three miles.

Park writes: "In places it approaches within 50 or 60 chains of the railway-line, from which it is separated by a strip of low sandhills. A short siding might easily be constructed to reach the limestone area, which is perfectly free of all superficial deposits, and consequently in opening quarries no stripping would be necessary.

"The great extension of this limestone on the coast between Waitotara and Nukumaru cannot fail to be of immense economic value to the Wanganui district, where road-metal, railway-ballast, building-stone, and material for harbour-works are so scarce. . . . At Nukumaru the amount of material is practically unlimited, and, being easily accessible to the railway-line, [the stone] should be supplied at a very low rate. The land occupied by the limestone is at present Crown land, and it would be a serious loss to this district if it were suffered to fall into private hands.

"The annexed section shows the surface exposure of the limestone, and its extension from the coast to the railway-line, a distance of about three miles:—

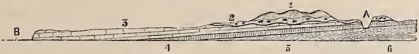

FIG. 1. NUKUMARU LIMESTONE, ETC.

1. Blown sands. 2. Yellow clays, sands and gravels of drift. 3. Nukumaru limestone. 4. Brown micaceous sandstones, with *Ostrea ingens*. 5. Yellowish-blue sandy clays. 6. Blue clays, with concretionary nodules.

A. Railway-cutting. B. Sea.

"The Nukumaru limestone occurs at sea-level, near the mouth of the Waitotara River, and slowly rises inland, occupying the tops of all the higher bush-clad ranges towards the sources of the Kai-iwi, Waitotara, Whenuakua, and Patea rivers." (Park, 1887 report, pp. 54–55.)

The Nukumaru limestone is described by Park as a coarse flaggy shell limestone, about 250 ft. thick, with well-rounded pebbles of quartz, grey sandstone, and dark slaty shale (1887 report, p. 53). At a lower horizon is another limestone about 50 ft. thick, composed of shells, corals, and Polyzoa (Bryozoa). This is seen in railway-cuttings about a mile south of the Waitotara railway-bridge, and on the left or south bank of the Waitotara River "opposite Wilkie's farm." (Park, 1887 report, p. 64.) About 150 ft. of soft sandstone intervenes between the two limestones.

Again, above the Nukumaru limestone is a series of loose sandy shell-beds with numerous bands of hard flaggy argillaceous limestone. These bands are seen on the coast west of Butler's Creek (between Okehu and Nukumaru).

In the Kai-iwi district there are several shelly beds that contain a fairly high content of carbonate of lime, and are suitable for local use as soil-dressings. These are well seen in some of the railway-cuttings and ballast-pits between Okehu and Kai-iwi stations.

In describing the calcareous deposits of the Wanganui River difficulty arises from the circumstance that the beds on opposite sides of the river, though alike, are in different counties. This illustrates the fact that though a large river may form an excellent boundary from some points of view, it is seldom or never a geological boundary. It may be added that, though possibly well adapted for separating minor political areas, rivers do not make good international boundaries.* For the reason indicated above, the Wanganui River limestones will now be described, irrespective of the bank on which they are situated.

At Kaiwaiki, about twelve miles above the town of Wanganui, a number of hard gritty cemented shell-beds or limestones occur at wide intervals in loose brown micaceous sands. They are nearly flat-bedded, and vary from a few inches to 50 ft. in thickness. The shell-beds are exposed in high escarpments along the banks of the river for several miles, and have been quarried at all available points from water-level to 500 ft. above the river. (Park, 1887 report, p. 50.)

Figure 2 represents the section seen by Park about 10 chains below the quarry wharf at Kaiwaiki.

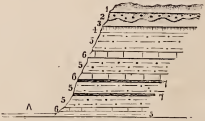

FIG. 2. SECTION NEAR KAIWAIKI QUARRIES.

A. Wanganui River. 1. Ferruginous sandy clays, 50 ft. 2. Rusty trachyte (? andesitic) cement-gravels, 20 ft. 3. Brown ferruginous sands, 15 ft. 4. Hard shell-bed, 10 ft. 5. Yellowish-brown micaceous sands, 410 ft. 6. Hard limestone bands, 65 ft. 7. Thin-bedded brown sands and light-coloured clays, 10 ft.

At Raorakia (Raorikia), four miles above Kaiwaiki, the blue clays contain concretionary nodules. At Parakino a shell-bed, 25 ft. or 30 ft. thick, is seen, interbedded with brown micaceous sandstones. Near Koriniti (or Corinth), forty miles from Wanganui, the blue clays contain numerous concretions and concretionary bands. Between Karatea, a few miles above Koriniti, and Hiruharama (or Jerusalem) concretionary blue clays are again seen. Further references to the calcareous rocks of the Wanganui River will be found in the section dealing with Waimarino County.

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* This view is held by Colonel Sir Thomas Holdich and many other authorities, but a contrary opinion, advocated by Professor L. W. Lyde, is beginning to gain ground. (See the *Geographical Review*, vol. 7, No. 4, April, 1919, pp. 201–19.)

The limestones represented by the following analyses probably come from Waitotara County :—

	(1)	(2)	(3)	(4)
Matter insoluble in acid, &c. ..	22·59	..	..	..
Alumina and iron oxides	4·94	..	..	..
Calcium carbonate	69·02	59·71	67·0	51·00
Magnesium carbonate	2·32	..	..	..
Water	1·13	..	..	..
	100·00	..	..	..

References.—(1) Shelly limestone from Waitotara, forwarded by Mr. D. Atkinson. Col. Mus. and Lab. 11th Ann. Rep., 1876, p. 17. Lab. No. 1797.

(2) From Waitotara district, forwarded by A. D. Bayfeild. Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab. No. E 488. Lime (CaO), 33·44 per cent. ; phosphoric anhydride (P_2O_5), 0·32 per cent.

(3) Calcareous deposit from the Wanganui district, forwarded by S. H. Drew. Col. Mus. and Lab. 22nd Ann. Rep., 1887, pp. 40–41. The residue from acid treatment consisted principally of " rolled quartz-gravel." This sample and also No. 4 may have come from Wanganui County.

(4) From " Wanganui," forwarded by E. N. Liffiton. Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 1137.

Summary of Limestone Resources and of Means of Transport.

Waitotara County appears to have considerable lime resources. The Nukumaru limestone in particular is conveniently situated, and, if the description given is correct, can supply practically unlimited quantities of stone. There is reason to fear, however, that the limestone is not high grade. This is an inference drawn (1) from the analyses quoted, which may or may not represent the Nukumaru limestone, and (2) from the lack of analyses showing that high-grade limestone exists in the county. It is plain that the statement made is not proved, but the doubt can be easily settled by obtaining representative samples of the limestone and having them analysed. The loose shelly sandy beds of the Kai-iwi district ought to be of considerable value for local application to the soil. Very little is known about the occurrence of limestone in the inland or northern part of the county. This district, together with the adjoining portions of Patea, Eltham, Stratford, and Whangamomona counties, requires exploration.

The coastal part of Waitotara County, with good roads, a railway, and the port of Wanganui, has good means of communication. The inland part is badly situated, except in so far as the Wanganui River is navigable for cargo-boats.

Literature.

References to the geology of Waitotara County are—

Rep. of Geol. Explor., No. 7, 1872, p. 182 ; No. 12, 1879, pp. 4, 5 ; No. 18, 1887, parts of pp. xl–xlii, 1, 29–31, 47–73, 171–72, 179, and map opposite p. 32 ; No. 21, 1892, p. 175 (Wanganui County). Park's report on the " Western Part of Wellington Provincial District," &c. (pp. 24–73 of No. 18), contains the only detailed account of the Wanganui and Waitotara districts to be found in the Geological Survey publications.

Dieffenbach, Ernest W. : " Travels in New Zealand," vol. 1, 1843, pp. 127–30.

Mantell, W. B. D., quoted by Mantell, G. A., in Quart. Jour. Geol. Soc., vol. 4, 1848, p. 239 (not seen).

Mantell, G. A., in Quart. Jour. Geol. Soc., vol. 4, 1848, pp. 225–41, and vol. 6, 1850, pp. 319–43 (not seen).

Trans. N.Z. Inst., vol. 1, 2nd ed., 1875, pp. 314, 322, &c. (Crawford); vol. 2, 1870, pp. 158–60 (R. Pharazyn), 163–64 (Buchanan), 351–53, 358, &c. (Crawford); vol. 7, 1875, pp. 453–57 (C. W. Purnell); vol. 15, 1883, pp. 410–11 (Hutton); vol. 18, 1886, part of pp. 336–67 (Hutton); vol. 25, 1893, pp. 343–50 (Hill); vol. 34, 1902, pp. 451–52 (J. T. Stewart).

Park, James: "The Geology of New Zealand," 1910, p. 389. (Passing mention of Waitotara limestone.) For other references see "Waitotara" and "Wanganui" in index.

The greater part of the town of Wanganui is in Waitotara County (municipal boundaries being disregarded), and most references to its neighbourhood or to the lower Wanganui River may be considered to apply to that county.

49. Wanganui County.

Wanganui County is a long but somewhat narrow strip of country extending from the sea-coast south of the Wanganui River to the far inland Waiouru district. It does not now contain the chief part of the town of Wanganui within its boundaries, and thus bears a resemblance to the play of Hamlet with the principal character left out. Waimarino and Waitotara counties are in a similar position. The geology of the greater part of Wanganui County is similar to that of Waitotara County. In the extreme north-east material of volcanic origin (aerial pumice, &c.) appears. It is not necessary here to do more than mention the large boulders of andesite, in places embedded in clay, that are found in this part of New Zealand, and are supposed by Park to be of glacial origin, an hypothesis that is improbable and remains unproved. Of much more importance is the plain-like surface of the southern part of the county, intersected by somewhat deep river-valleys. This surface slopes gently down to the sea, and is continued throughout the coastal belt to the northward into Taranaki. In a sense it is seen all round Mount Egmont, and by the joining-up of hill and ridge tops is continued inland to the foot of Mount Ruapehu and the Ruahine Range. Moreover, the hilly country of North Taranaki is part of the same feature, probably more dissected and eroded than elsewhere. The name "Wanganui coastal plain" has been applied to the surface under description, but it is actually a complex feature, for which the term "coastal plain" is not altogether suitable. As the Wanganui "plain" continues southward, the underlying Pliocene sedimentaries become more and more masked by gravels. In a broad sense all the level or nearly level country on the west side of the Ruahine and Tararua ranges, as far south as Paraparaumu, less than thirty miles north of Wellington, is part of the Wanganui "plain." As described, the "plain" possesses a certain degree of unity. This is perhaps exemplified by the fact that Wanganui and Rangitikei counties stretch back to its northern limits, whilst several other counties, with their chief settlements on the flatter lands, include considerable areas of hilly country that in the ordinary sense are very far indeed from being part of a plain.

Little is known about limestone in Wanganui County beyond that implied in the description of Waitotara County given above. Shelly beds are well seen east of the Wanganui River at Shakespeare Cliff, Putiki (or Landguard) Bluff, &c. Inland, shelly limestone will no doubt be found at many places.* It is clear that geological exploration is as much needed in Wanganui County as in parts of Waitotara and many other districts.

If the Nukumaru limestone is of sufficiently good quality it is capable of conveniently supplying all the needs of the southern part of Wanganui County, and in addition

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* B. C. Aston (*loc. cit.*, p. 99) has recently published a part analysis of a sample of limestone from Mataroa with 92·5 per cent. of carbonate of lime.

A. Calcareous Strata, Wanganui River.

B. Limestone near Rockville, Collingwood County.

Note the nearly horizontal bedding.

there are the shelly beds and shell-limestones of the lower Wanganui River. The means of distribution, with the railway as a base and the Wanganui River and good roads as minor arteries, are good. If necessary, lime can be imported from the Riwaka or the Golden Bay districts to the port of Wanganui, which can now be entered by vessels with a carrying-capacity of from 2,000 to 3,000 tons. The sea voyage involved is between 120 and 130 statute miles.

The central part of Wanganui County appears to be almost unsettled, and has poor road and no railway communication. The north-eastern part is traversed by the Main Trunk Railway, and could obtain lime from the Te Kuiti district, but the railway haulages are much over a hundred miles, the distance by rail from Te Kuiti to Waiouru (just outside the boundary of the county) being 116 miles, and to Mataroa (near Taihape) 134 miles. Whether the lime situation will ever be improved by the construction of a railway from Taihape, Waiouru, or some other point to the limestone deposits of the Upper Rangitikei Valley cannot, of course, be definitely stated.

Literature.

The geological literature relating to Wanganui County centres about the town of Wanganui and the Wanganui River. The publications listed under Waitotara County therefore apply to Wanganui County, or to a part of it. The following papers have reference to the supposed glacial evidences found in the Hautapu Valley, &c.:—

Trans. N.Z. Inst., vol. 42, 1910, pp. 575–80, 580–84, 589–612 (all by Park); vol. 48, 1916, pp. 135–37 (Park). See also "The Geology of New Zealand," 1910, pp. 194–95. Park's views have been vigorously opposed by Marshall. The controversy was reported chiefly by newspapers during 1909. See, however, Marshall's "Geology of New Zealand," p. 203.

Trechmann, C. T.: "The Glacial Controversy in New Zealand." Geol. Mag. Dec. VI, vol. 4, No. 6, June, 1917, pp. 241–45. See pp. 242–43.*

50. RANGITIKEI COUNTY.

Rangitikei County has the shape of a thigh-boot with the toe cut squarely off. At the toe and heel are the Early Mesozoic or perhaps Palæozoic rocks of the Kaimanawa and Ruahine mountains; between is an area of Pliocene conglomerate, sandstone, claystone, and limestone, which extends down the Rangitikei River valley past the ankle to and far beyond the awkward-looking knee. South of the hills in the Hunterville district the Pliocene rocks are hidden by the gravels of the Wanganui Plain, except where the streams have cut deep guts in the plain. A belt of sandhills fringes the coast-line of this and other counties abutting on the shores of the Wanganui Bight. (The name "South Taranaki Bight" ought to be equally applicable to the bight, but on official maps it is attached to an insignificant indentation of the coast-line opposite Hawera.)

Apart from two small patches of limestone near Hunterville and Taihape (or Utiku), the calcareous claystones of the Lower Rangitikei Valley, and the calcareous concretions they contain, the only known limestone in the county is in the foot mentioned above, and especially in the instep region.

Hector states that on the south-east side of the Kaimanawa Mountains, "in the depression between them and the west side of the Ruahine Range, the Tertiary limestones occur, forming a wide belt of open grassy country, and are continued to the west as a succession of scarps, or edges, encircling the volcanic zone (Ruapehu, &c.), and dipping to the south-west" (1871 report, p. 161).

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* In reply to Dr. Trechmann, Professor Park has written "Pleistocene Glaciation of New Zealand." Geol. Mag., Dec. vi, vol. 5, No. 9, September, 1918, pp. 394–97.

Park states that in the Moawhango Valley near Erewhon (a few miles north-north-east of Moawhango Township) a band of coarse flaggy limestone 50 ft. thick is exposed. This is underlain by 200 ft. of blue sandy clays, with argillaceous calcareous bands, below which comes 10 ft. of coarse shelly limestone. The flaggy limestone (50 ft. band) is composed of broken shells and sandstone pebbles. Near the old rocks of the Kaimanawa Range it passes into a pebbly conglomerate. The Upper Rangitikei River has cut out its channel through several bands of hard shell-limestone, yellow and blue sandy clays, &c. East of the river in the neighbourhood of Erewhon a coarse flaggy limestone 60 ft. thick occurs on the higher ground, and runs out against the old rocks of the Ruahine Range at an altitude of 3,450 ft. above the sea. This limestone also cape a number of flat-topped hills on both sides of the Rangitikei (1887 report, pp. 37–39). In a later report Park incidentally gives further details of the limestone in the Upper Rangitikei Valley (1890, pp. 64–67). Hill describes Erewhon (Birch's station) as being in the centre of a plateau with limestone-topped hills. From Moawhango for about eleven miles to the north-north-west the country consists of limestone inter-bedded with calcareous sands. On the border of the volcanic basin the limestones present a series of remarkable scarps in the direction of Ruapehu (1890 paper, pp. 425–26). The highest limestone appears about midway between Erewhon and Ruapehu, at a height of 4,270 ft. (p. 429). Hill's description agrees with that of Hector, summarized above. The locality where the scarps appear may be in any one or all of the three counties, Waimarino, Wanganui, and Rangitikei.

At an unidentifiable point on the right or western bank of the Hautapu River (probably some miles south of Taihape) coarse shelly limestone outcrops over a small area near the top of a hill. Farther north, blue clays with shell-beds are seen at the Hautapu Falls (Park, 1887, pp. 36–37). Two miles northward of Hunterville, on the road to Pukiori clearing, a cemented sandy shell-bed or limestone occurs (Park, 1887, pp. 35–36).

The following analyses of limestone are reported from Rangitikei County :—

	(1)	(2)	(3)	(4)	(5)	(6)
Insoluble matter, &c.	14·83	6·5	0·8	..	6·97	..
Alumina and iron oxides	2·64	0·4	Trace	..	0·08	..
Calcium carbonate	80·11	91·1	98·9	91·11	75·11	55·9
Magnesium carbonate	0·56	1·7	0·3	..	4·09	..
Moisture, undetermined, &c. ..	..	0·3	..	..	13·75	..
	98·14	100·0	100·0	..	100·00	..
Quicklime in calcined stone, per cent. (Aston)	71	85	98	86·8	79	..

References.—(1) From Bull's (?). Aston, B.C., in Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 238. Analyst's No. G 45 ; year of analysis, 1906.

(2) and (3) From Marton (?). Forwarded by A. R. Mackay. Same reference as No. 1. Col. Lab. 34th Ann. Rep., 1901, p. 13. Lab. Nos. B 77 and B 78. No. 3 analysis (B 78) probably represents a sample of stalactite or of vein calcite. Sample B 77 was brownish in colour.

(4) From Ohutu, via Utiku, forwarded by Secretary, Agricultural Department. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 324.

(5) From Utiku. Same reference as No. 1. Analyst's No. G 49 ; year of analysis, 1915.

(6) Soft limestone, Taihape district. Aston, B. C., in Jour. Agri., vol. 17, No. 2, Aug., 1918, p. 99. Analyst's No. H 340.

Summary of Limestone Resources and of Means of Transport.

The greater part of the remarks made concerning the supply of lime for Wanganui County applies to Rangitikei County. At present nearly the whole of the county must look abroad for its lime, which apparently must come from Nukumaru or from Nelson via Wanganui. The New Plymouth - Wellington Railway passes through the southern part of the county, and the Main Trunk line intersects the eastern middle part from Marton to Taihape. The western middle part and the northern part are more or less unsettled and unroaded. If the boot metaphor be employed again, one could say that the top of the leg, its back, and the ankle have good road and railway communications, the knee and the foot poor roads and no railways. Probably at some future time a railway will be made into some part of the foot, and this may tap good limestone.

Literature.

Among the references to the geology of Rangitikei County are—

Rep. of Geol. Explor., No. 5, 1869, pp. i–ii; No. 6, 1871, part of pp. 158–64; No. 18, 1887, part of pp. xl–xlii, xlix, 25, 26, 28–31, 35–40, 51, 58–60, 65, 68, 69, &c., and map opposite p. 32; No. 20, 1890, pp. 64–67; No. 21, 1892, p. 161.

Trans. N.Z. Inst., vol. 2, 1870, pp. 353–54, &c. (Crawford); vol. 11, 1890, part of pp. 422–29 (Hill).

Parl. Paper C.–10, 1901, part of pp. 12–21 (bound in Mines Rep.).

51. KIWITEA COUNTY.

The geology of Kiwitea County is similar to that of adjoining parts of Rangitikei County. In the extreme north-east are the old Mesozoic rocks of the Ruahine Range. The rest of the county is underlain by Tertiary sandstones and claystones, with possibly some limestone. In most places these rocks, as for example on the east side of the Rangitikei opposite Mangaweka, are capped by gravel and other alluvial deposits of Pleistocene or Recent age. It is possible that at the foot of the Ruahine Range fault-involved limestone with a steep or vertical dip will be found to outcrop, in the same way as at the east end of the Manawatu Gorge.

Kiwitea County will probably have to look far afield for its lime; and since no railway enters it, lime will presumably be an expensive commodity for many years to come. The Main Trunk Railway passes close to its western border, and the residents of the county no doubt hope some day to have railway communication with Feilding or some other point on the Wellington–Auckland line.

Literature.

The only references to the geology of Kiwitea County found in the literature consulted are—

Rep. of Geol. Explor., No. 18, 1887, map opposite p. 32, and casual references to the "drift formation" between the Ruahine Ranges and Mount Egmont; No. 20, 1890, p. 66 (supposed coal — really carbonaceous shale — on Porangaki (Pourangaki) Stream).

52. POHANGINA COUNTY.

Practically all that has been said about Kiwitea County applies to Pohangina County. It has a greater share of the Ruahine Range. Some poor limestone occurs near Apiti, and in the Pohangina Valley, probably near the foot of the Ruahine Range.

The available analyses are—

	(1)	(2)	(3)	(4)	(5)
Matter insoluble in acid	..	41·14	23·02	22·01	32·68
Alumina and iron oxides	..	3·80	1·84	2·00	2·18
Calcium carbonate	73·20	52·60	74·43	75·86	63·11
Magnesium carbonate and undetermined ..	..	2·46	0·71	0·13	2·03
	..	100·00	100·00	100·00	100·00
Quicklime in calcined stone, per cent. (Aston)	..	..	62	64	50

References.—(1) From Pohangina Valley, forwarded by J. D. Maclaurin. Dom. Lab. 42nd Ann. Rep., 1909, p. 21. Lab. No. 1964. Lime (CaO), 41·00 per cent.; carbonic anhydride (CO_2), 32·20 per cent.

(2) (3) (4) From Apiti, forwarded by D. Hogan. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. Nos. E 386/1, 2, 3. Nos. E 386/2, 3 represent "poor stones; might be used in the unburnt state if cheaply applied."

(5) From Apiti, Aston, B.C. in Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 239. Analyst's No. F 6. Date, 1915.

None of these limestones is suitable for calcination, but recently B. C. Aston has recorded an analysis of hard crystalline limestone from Apiti with 97·5 per cent. of $CaCO_3$ (Jour. Agri., as previously cited, p. 99). He also gives an analysis of calcareous sandstone from Apiti with 50·4 per cent. of $CaCO_3$ (same publication, p. 100).

Literature.

The references to the geology of Pohangina County found in the literature consulted are—

Trans. N.Z. Inst., vol. 2, 1870, p. 358 (J. C. Crawford).

Rep. of Geol. Explor., No. 10, 1877, p. 86; No. 18, 1887, pp. xli, 26–28, 34–35, 62, and map opposite p. 32; No. 22, 1894, p. 2.

53 and 54. Waipawa and Waipukurau Counties.

The geology of Waipawa County resembles that of the inland part of Hawke's Bay, but Cretaceous or supposed Cretaceous rocks are better developed. With Waipawa may be described the small adjoining county of Waipukurau, which is composed of similar rocks, the greywackes and argillites of the Ruahine Range perhaps excluded. The chief limestone of the two counties is probably of Pliocene age, and may provisionally be correlated throughout with the Te Aute limestone mentioned in the description of Hawke's Bay. There may be some Miocene limestone also, but the Cretaceous rocks, though calcareous, do not appear to contain any limestone of consequence.

The limestones of the Whakarare, Whakarara, or Wakarara Range, near Kereru, extend southward, though apparently as disconnected patches, through the western part of Waipawa County. Limestone occurs at or near Ashley-Clinton, but only one sample from this locality, and that not of good quality (No. 2. of table on next page), has been analysed in the Dominion Laboratory.

The Te Aute limestone and associated beds pass southward into Waipawa County, and are well developed west of Kaikora (now Otane), and again west of the town of Waipawa. The Waipawa County map shows a limestone reserve on the south bank of the Waipawa River, three miles west of the town of Waipawa. Except where interrupted by river-valleys or hidden by younger deposits, the Te Aute limestone and the associated beds, according to McKay's map of 1877, continue far to the southward as a belt of varying width. West of Waipukurau the railway crosses to the west side of the belt, and consequently east or east-south-east of Takapau limestone is developed as illustrated by the subjoined section (fig. 3).

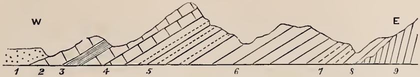

Fig. 3.—Section from Takapau Railway-station east to Johnston's Woolshed.

1. Gravels of Ruataniwha Plain. 2. Band of shelly limestone. 3. Sandy clay-marls (not clearly seen in this section, but showing farther north). 4. Lower thick band of Te Aute limestone. 5. Brown sands and grey sandy clays with shells. 6. Grey sandy beds, fossiliferous. 7. Grey sandy beds with bands of brown and green sands, the latter full of small shells and Foraminifera. 8. White clays, with minute plant-fragments. 9. Old Secondary (Mesozoic) rocks forming Woolshed Hill.

Bed No. 2 consists of shell-remains, and is apparently considered by McKay to represent the upper part of the Te Aute limestone. The upper part of bed No. 4 consists of hard consolidated rock. Under this is a much more friable or softer layer (bed 5 of section) consisting mainly of comminuted *Balanus* shells. This is followed downward by a soft yellowish calcareous rock, "wholly formed of shell sand." The thickness of this bed is stated by McKay to be "not far short of 100 ft.," but in the next paragraph he states that the calcareous rocks, by which he apparently means beds Nos. 2 to 5 inclusive, have a thickness of from 100 ft. to 130 ft. One must suppose that he really intended to specify only the beds Nos. 2 to 4 (1887 report, pp. 186–87). South of Takapau the Te Aute limestone continues into Dannevirke County.

Calcareous concretions occur in the Cretaceous rocks at many places—for example, at Waipawa Gorge. Here also soft rocks of calcareous character, called by McKay "chalk marls," are well seen, and on the south side of Waipawa River form high cliffs (1879 report, p. 73). Similar rocks appear near Kaikora (or Otane), and on the slopes of Mount Vernon, a hill near Waipukurau.

The available analyses of limestone from Waipawa and Waipukurau counties are given in the subjoined table:—

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid	22·72	..	1·18	..	..	4·39
Alumina	0·64	..	0·97	0·75	1·40	1·82
Iron oxides	0·81	..				
Calcium carbonate	74·62	66·0	94·67	96·95	92·01	92·76
Magnesium carbonate	1·21	..	2·49	..	..	1·03
Water	..	..	0·18	..	..	..
Organic matter	..	..	0·51	..	..	..
	100·00	..	100·00	..	..	100·00
Quicklime in calcined stone, per cent. (Aston and others)	62·8	..	94·2	94·7	86·9	87

	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Matter insoluble in acid	3·50	3·10	4·80	14·40	11·40	10·30	0·20
Alumina	1·50	0·60	1·10	2·50	2·10	3·20	0·20
Iron oxides							
Calcium carbonate	95·00	95·20	93·00	80·90	84·90	86·10	99·60
Magnesium carbonate	..	..	..	..	..	..	..
Water, &c...	..	1·10	1·10	2·20	1·60	0·40	..
Organic matter	..	..	..	..	..	..	..
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Quicklime in calcined stone, per cent. (Aston)	91	93	90	73	80	78	99

References.—(1) Rubbly sandy limestone from Kaikoura (*i.e.*, Kaikora), forwarded by the Superintendent of Hawke's Bay Province (Hon. J. D. Ormond). Col. Mus. and Lab. 9th Ann. Rep., 1874, pp. 15–16. Lab. No. 1418/6.

(2) Compact subcrystalline limestone from Ashley-Clinton (western Waipawa), forwarded by Mr. W. Morton. Col. Lab. 30th Ann. Rep., 1897, p. 12. Lab. No. 7330.

(3) Compact brownish limestone from Newlands, Waipukurau, collected by Dr. (Sir James) Hector. Col. Mus. and Lab. 13th Ann. Rep., 1878, p. 21. Lab. No. 1940.

(4) (5) From Mount Herbert, Waipukurau, forwarded by Mr. J. D. Todd. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. Nos. A 131/1, 2.

(6) From Waipukurau, forwarded by the Rabbit Inspector. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 922.

(7) to (13) From Hatuma (south-west of Waipukurau and near Takapau). Aston, B. C., Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 240. Analyst's Nos. E 135, 136, 137, 138, 139, 140, 141. Analysis E 141 cannot well represent a large body of stone—the material is too high-grade.

In 1917 Dr. J. Henderson, of the Geological Survey, collected a sample of limestone from a quarry beside the railway-line, a mile and a half south of Pukehou. This represented 20 ft. of friable shelly limestone, and on analysis yielded 80·20 per cent. of calcium carbonate, 0·14 of phosphoric anhydride, and 15·55 of matter insoluble in acid. (Lab. No. H/1653.) A sample was also obtained from a bed of soft massive limestone, 100 ft. thick, one mile south-east of Takapau Railway-station This yielded on analysis 64·40 per cent. of calcium carbonate, 0·11 of phosphoric anhydride, and 28·56 of matter insoluble in acid. (Lab. No. H/1652.)

Summary of Limestone Resources and of Means of Transport.

The available information indicates that Waipawa and Waipukurau counties are well supplied with limestone, much of which is of high grade and suitable for calcination. Attention may be drawn to the fact that friable limestones and highly calcareous sands occur in various places—for example, east of Takapau. On the whole the two counties have good transport facilities. The Wellington–Napier Railway runs through the eastern part of the two counties (considered as one area), and passes near some of the best limestone deposits. Good roads exist in most of the settled districts. In some of the more remote settlements towards the Ruahine Range, such as Ashley-Clinton and Kereru, local deposits of limestone may compensate for the want of easy communication with the rich limestone country to the east.

Literature.

Much of the literature listed under Hawke's Bay applies to Waipawa and Waipukurau counties. The following papers and reports may be mentioned here:—

Rep. of Geol. Explor., No. 10, 1877, part of pp. 67–94; No. 12, 1879, pp. 69–75; No. 18, 1887, part of pp. 182–89, and scattered references on later pages.

Parl. Paper C.–10, 1901, part of pp. 32–34 (bound in Mines Rep.).

Trans. N.Z. Inst., vol. 20, 1888, part of pp. 293–306 (Hill, on Distribution of Pumice); vol. 25, 1893, pp. 350–53 (Hill); vol. 27, part of pp. 451–66 (Hill).

55. PATANGATA COUNTY.

Cretaceous rocks, chiefly concretionary sandstones and chalk marls, according to McKay form almost the whole of the southern part of Patangata County, and extend along its western border to a point near the township of Patangata. They cover also a considerable area east of Patangata, and in this direction reach the coast, along which they are seen for some miles. Tertiary sandstones, claystones, and limestones extend from Patangata north-east and also south-east to the coast, and occur as a small patch at Cape Turnagain.

So far as can be ascertained, limestone, probably of Upper Miocene or Pliocene age, occurs somewhat abundantly near Patangata, and thence extends north-east to the coast. McKay shows Te Aute limestone as forming the top of the hill or ridge west of Te Apiti. A thick bed of limestone occurs at Cape Turnagain (see analysis No. 4 below), and there is probably also limestone west or north-west of Wanstead near the western boundary of the county. The available information does not enable an exact statement of the limestone localities to be made. There seems to be an abundance of calcareous claystone and similar rocks, with numerous calcareous concretions and concretionary bands, but as a rule these are not valuable as a source of lime.

The recorded analyses of calcareous material from Patangata County are—

	(1)	(2)	(3)	(4)	(5)
Matter insoluble in acid ..	24·94	..	..	25·80	..
Alumina	20·50	..	..	7·40	..
Iron oxides	Trace	..	..		
Calcium carbonate ..	46·98	57·80	61·21	66·80	84·60
Magnesium carbonate ..	0·74	..	..	..	..
Iron carbonate	5·56	..	..	..	..
	98·72	..	..	100·00	..

References.—(1) Argillaceous pale-yellow limestone from Pukekura, forwarded by H. Hartree. Col. Mus. and Lab. 24th Ann. Rep., 1890, p. 27. Lab. No. 5099.

(2) (3) Marl from Pukekura, forwarded by H. Hartree. Same publication as No. 1 pp. 27–28. Lab. Nos. 5150/1, 2, Residue after acid treatment, fine sand and clay. "Both marls would prove useful for top-dressing clayey soils deficient in lime." Pukekura is a hill north-west of Wanstead, and it is supposed that the samples came from that locality. The above analyses (Nos. 1, 2, and 3) are also given under "Hawke's Bay." (See p. 114.)

(4) Hard "calcareous sandstone" (arenaceous limestone) from Wainui (Herbertville), forwarded by S. Franklin. Col. Mus. and Lab. 18th Ann. Rep., 1883, p. 44. Lab. No. 3374. The sample probably came from the limestone at Cape Turnagain. (See list on p. 65 of report cited.)

(5) From Patangata, forwarded by H. E. Tiffen. Dom. Lab. 47th Ann. Rep., 1914, p. 21. Lab. No. D 1078.

Summary of Limestone Resources and of Means of Transport.

Patangata County is well supplied with calcareous rocks, but further exploration is needed in order to ascertain the amount, distribution, and quality of the various limestones. Of the five analyses quoted above, only the last gives any indication of good stone. The Napier–Wellington Railway passes through the north-western corner of the county, and that part can therefore conveniently draw on the limestones of Waipawa and Hawke's Bay counties, as well as on its own resources. The western border of the county to some miles south of Wanstead is probably also fairly well situated with respect to limestone deposits in the adjoining parts of Waipawa, Waipukurau, and perhaps Dannevirke counties.

Literature.

Most of the literature cited under Waipawa and Waipukurau counties applies to Patangata. The following references may here be given:—

Rep. of Geol. Explor., No. 9, 1877, pp. 43–53; No. 12, 1879, part of pp. 69–75; No. 18, 1887, pp. 189–91, map opposite p. 192, and casual references; No. 19, 1888, pp. xl, 88–90; No. 21, 1892, pp. 159–60.

Trans. N.Z. Inst., vol. 20, 1888, pp. 293–306 (Hill); vol. 26, 1894, part of pp. 392–96 (Hill).

56. Dannevirke County.

Old Mesozoic rocks form the backbone of Dannevirke County—that is, the Ruahine Range—and appear at the north end of the Puketoi Range in the valley of a tributary of the Mangatoro Stream. (J. Henderson, 1914 report, p. 103.) There may possibly be other isolated outcrops. The rest of the county appears to be covered by Miocene and Pliocene conglomerates, sandstones, claystones, and limestones, or by Pleistocene and Recent gravels, &c.

The Takapau or Te Aute limestone extends southward into Dannevirke County, and is found near Ormondville, Mangahei, and Mangapuaka. Close to the Manawatu River, a mile and a half from Ormondville, is a cave in shelly limestone, which has been specially described by H. N. McLeod in the Transactions of the New Zealand Institute. This district apparently contains more limestone than any other part of Dannevirke County. Farther south, near the watershed at sixteen or seventeen miles on the road from Dannevirke to Weber, a fairly thick limestone appears. On the top of Oparae Hill (north end of Puketoi Range), at a height of 2,471 ft., is a bed of gritty limestone underlain by calcareous claystone, which again is underlain by another band of limestone. These beds have a westerly dip. Three or four miles east of Dannevirke gritty calcareous bands occur, interbedded with blue calcareous claystones.* These have a dip of about 12° to the westward. There may be a certain amount of fault-involved limestone at the eastern base of the Ruahine Range. McKay mentions the supposed occurrence of limestone in the Makaretu Gorge (1877 report, p. 75). Hill states that the greensands of Kereru Stream, five miles from Weber, contain concretionary bands of impure limestone (1894 paper, p. 395).

The following analyses represent limestones from Dannevirke County. All apparently come from the north-east part of the county—that is, from the district east of the railway-line, between Dannevirke and Ormondville :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Silica, or matter insoluble in acid	..	18·50	..	9·06	4·28	12·59	34·26
Alumina	..	3·80	..	2·22	1·38	3·44	3·48
Iron oxides	..	1·70	..				
Lime	(45·4)	40·40	51·18	(49·10)	(50·50)	(45·57)	(33·36)
Magnesia	..	0·80	..	Trace	..	..	..
Carbonic anhydride	(35·6)	32·10	40·22	(38·57)	(39·67)	(35·81)	(26·21)
Water	..	..	..	1·05	4·04	2·02	2·11
Alkalies and undetermined ..	..	2·70	..	..	0·13	0·57	0·58
	..	100·00	..	100·00	100·00	100·00	100·00
Calcium carbonate (per cent.) ..	81·0	72·50	91·40	87·67	90·17	81·38	59·57
Quicklime in calcined stone (per cent.)	70·5	61·96	85·6	81	..	..	..

(1) Limestone from Mangahe (Mangahei), forwarded by Messrs. Buick and Russell. Col. Lab. 40th Ann. Rep., 1907, p. 16. Lab. No. 942.

(2) From Whiteburn, near Ormondville, forwarded by Mr. Charles A. Copeland. Same publication as No. 1, p. 17. Lab. No. 529. The sample is said to be from an extensive deposit. It is suitable for the manufacture of Portland cement.

(3) From Mangapuaka, forwarded by Mr. Walter Dassler. Dom. Lab. 42nd Ann. Rep., 1909, p. 20. Lab. No. 1799.

(4) From Makotuku, near Ormondville. Aston, B.C., Jour. Agric., vol. 11, Sept., 1915, p. 240. Analyst's No. L 937. Date, 1910. See also Dom. Lab. 43rd Ann. Rep., 1910, p. 52.

(5) to (7) Aston, B. C. : 11th Ann. Rep. Dept. Agric., App. I, Chem. Division, 1903, p. 17. Analyst's numbers, D 189, 190, and 191. The samples were forwarded by Mr. W. G. Wallace, Ormondville.

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* Similar bands with an easterly dip occur about three miles west of Dannevirke.

Summary of Limestone Resources and of Means of Transport.

Though the limestone deposits east and south of Ormondville are fairly extensive, Dannevirke County as a whole is probably not well supplied with high-class limestone. There is no lack of calcareous claystones, and in places these could be effectively used as soil-dressings. The county can easily import lime from Waipawa and Hawke's Bay counties. It is traversed by the Napier–Wellington Railway, and the roads for some miles on either side of the railway are excellent, so that there will be no difficulty in distributing imported lime over the more closely settled districts.

Literature.

The chief references to the geology of Dannevirke County are the following:—

Rep. of Geol. Explor., No. 10, 1877, pp. 75, 80, 81, 87, 91, 92, &c., and map opposite p. 88 (which, however, greatly exaggerates the limestone area); No. 15, 1883, pp. x–xi, 1–4.

Parl. Paper C.–10, 1901, pp. 26–28, 32–34 (bound in Mines Rep.).

Trans. N.Z. Inst., vol. 26, 1894, pp. 392–96 (Hill); vol. 33, 1901, pp. 343–44 (H. N. McLeod, on cave at Papatu, near Ormondville).

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2 (Mines Rep.), 1914, part of pp. 131–35 (2nd ed., 1915); 9th Ann. Rep., part of Parl. Paper C.–2, 1915, p. 103 (J. Henderson).

57. OROUA COUNTY.

Oroua County may be said to form part of the Wanganui Plain. In the extreme east it abuts on the Ruahine Range, the rocks of which have been previously mentioned. Much of the county is covered with gravel or other alluvial deposit, but at Manawatu Gorge calcareous claystones and fine sandstones of Pliocene age are exposed on the banks of the Manawatu River. Similar rocks are seen at various other points, and no doubt underlie the superficial deposits throughout the county. A section exposed in the banks of the Pohangina near Ashhurst has been described by Park (1887, pp. 34–35).

The following analysis refers to a sample reported to come from Makino, near Feilding:—

Matter insoluble in acid	12·00
Alumina and iron oxides	2·92
Calcium carbonate	83·57
Magnesium carbonate, &c.	1·00
	99·49
Quicklime in calcined stone (per cent.)	74

Reference.—Shelly rock from Makino. Aston, B. C., Journ. Agric., vol. 11, No. 3, Sept., 1915, p. 239. Analyst's No. K 2952. Date, 1909.

Means of Transport, &c.

Oroua County has no known limestone deposits of any value, but most of it is within easy reach of railways, and the distribution of imported lime offers no difficulty. Impure limestone occurs alongside the railway-line at the east end of the Manawatu Gorge, but the nearest likely source of supply at the present time is at Mauriceville. From Mauriceville to Ashhurst the railway haulage is about forty-five miles; to Feilding via Palmerston North, sixty-six miles; and to Kakariki, near the Rangitikei River, which forms the western boundary of the county, another eleven miles. Lime could also be imported from the district between Dannevirke and Napier. From Makotuku and Ormondville the railway haulage is shorter than from Mauriceville, but from Takapau northwards the distances are greater.

Literature.

There is hardly any literature relating to the geology of Oroua County. Its geology is roughly sketched in the map opposite p. 32, Rep. of Geol. Explor. No. 18, 1887; and a section near Ashhurst is described and figured on pp. 34–35; see also p. 62. Some of the references to Manawatu Gorge, the Rangitikei River, &c., may apply to Oroua County. See also No. 61, Kairanga County. Rep. Geol. Explor. No. 21, 1892, p. 159, briefly sketches the geology of Oroua County.

58. WOODVILLE COUNTY.

The geology of Woodville County is similar to that of Dannevirke County to the north and of Pahiatua County to the south. Old Mesozoic rocks are seen to form the Ruahine Range in the west, and may possibly appear in the Mangatoro watershed at the foot of the Puketoi Range. An alluvial plain surrounds Woodville. Pliocene conglomerates, sandstones, claystones, and limestones are the prevailing rocks, if the superficial deposits are disregarded. The limestones are generally impure and not very thick. They are best seen at the Manawatu Gorge, where they are involved in a great fault. According to McKay a low shell-limestone range strikes north (? north-east) from the junction of the Mangatainoka with the Manawatu (1877 report, pp. 74, 76). Limestone occurs extensively on the crest of the Puketoi Range, but probably not over any large area within the county. The only locality where the limestone has been geologically examined is Manawatu Gorge. From the accounts given by McKay (1877), Park (1887), and Henderson (1916) it appears that there are several limestone layers, intercalated with calcareous conglomerate and sandstone. According to the last-named writer the limestone beds are formed mainly of shell-fragments, and contain throughout numerous grit-particles and occasional layers of rounded pebbles. They vary rapidly, both along the strike and to the dip. The limestone band seen above the Gorge Railway-station is perhaps 40 ft. thick, but to the dip grades into a calcareous sandstone containing numerous scattered stones. It is not likely, however, that the variation along the strike will be as marked as that to the dip. In this locality the strike varies between 25° and 40° east of north, while the dip is about 40° to the south-eastward, lessening on the hill-tops. North of the Gorge Railway-station, at the quarry where the Railway Department was obtaining ballast in 1915, the limestone layers are thicker, and contain fewer grit-particles. The strike is here about 70° east of north, with a dip of 60° to the south-south-east. This locality is much better suited for the opening of a quarry to supply limestone for agricultural purposes than that near the Gorge Railway-station. The rock is here more friable, contains less grit and fewer pebbles, and the amount available for quarrying is many times greater. (Henderson, 1916, p. 30.)

The following analyses of limestone from Woodville County are available:—

	(1)	(2)	(3)	(4)	(5)	(6)
Silica, or matter insoluble in acid ..	2·65	15·39	13·30	..	16·02	13·10
Alumina	Trace	2·18	2·38	..	1·40	0·49
Iron oxides	1·91					
Calcium carbonate	92·16	79·44	83·91	80·70	80·89	85·78
Magnesium carbonate, &c.	2·96	..	0·41	..	0·48	..
Water	0·32	..	..	..	..	..
	100·00	97·01	100·00	..	98·79	99·37
Quicklime in calcined stone (per cent.) (Aston and others)	89·6	68·4	75	70·1	72	78

References.—(1) Porous limestone from Manawatu Gorge, forwarded by Mr. A. Hogg, M.H.R. Col. Lab. 31st Ann. Rep., 1898, pp. 11–12, 43. Lab. No. 7805.

(2) From Manawatu Gorge, forwarded by Director of Fields. Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 114. "This material appears similar in texture to the Mauriceville limestone."

(3) From Manawatu Gorge. Aston, B. C., publication cited on former pages (1915), p. 239. Analyst's No. G 229. Date, 1915. Sample similar in texture to Mauriceville stone.

(4) Near Woodville, forwarded by J. B. Blaine. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 223.

(5) (6) From Woodville. Same reference as No. 3. Analyst's numbers G 292 A and B. Date, 1906. Samples described as rock-limestone and shell-limestone.

The Manawatu Gorge limestone has been described by Mr. B. C. Aston, who in 1915 visited the deposits in company with Dr. J. Henderson. (See Jour. Agri., vol. 11, No. 5, Nov., 1915, pp. 403–5, and illustrations.) Aston also describes a low-grade calcareous deposit occurring a mile north of Ngawapurua Railway-station, which is three miles south of Woodville. He gives the following analyses (same article, p. 410):—

Lab. No.	Locality.	Insoluble Matter (Sand, &c.).	Alumina and Iron Oxides.	Calcium Carbonate ($CaCO_3$).	Magnesium Carbonate, &c.	Approximate Yield of Quicklime (CaO) in Calcined Limestone.	Remarks.
		Per Cent.	Per Cent.	Per Cent	Per Cent.	Per Cent.	
G 437	Ngawapurua	54·9	4·0	40·2	0·9	..	Medium hard stone.
366	Manawatu Gorge (top of outcrop above Gorge Station)	11·4	2·3	85·1	1·2	76	..
367	Taken below G 366 ..	21·9	2·9	73·9	1·3	61	..
368*	Railway-siding ..	19·6	3·6	75·7	1·1	63	Soft deposit containing 10·1 per cent. water.
369*	Cave, railway-siding ..	23·1	4·6	71·5	0·8	59	Very soft calcareous deposit, containing 14·2 per cent. water.
384	Railway Department's quarry	17·0	3·1	78·8	1·1	67	..
385	Top of cliff above Gorge Station	16·8	3·2	79·2	0·8	68	..

* Analysis made on the sample dried to constant weight on water-bath.

Summary of Limestone Resources and of Means of Transport.

Woodville County may be able to obtain pulverized limestone from the deposits near Manawatu Gorge, but the stone there is too uneven and uncertain in quality to be suitable for calcining. Thorough sampling of the Gorge limestone is necessary before taking any steps to establish a pulverizing plant. In the meantime the county could be supplied with better material from Mauriceville (thirty-seven miles from the town of Woodville by rail), or perhaps from Ormondville and Takapau, which are even nearer to the central and northern parts of the county. Farther north high-grade limestone may be obtained at various points near the railway to Napier. The last-named town is only ninety-five miles from the town of Woodville, and is therefore within the distance-limit at present allowed by the Railway Department for the free carriage of lime.

Literature.

The chief references to the geology of Woodville County will be found in the following reports. More than half of these deal with the copper-ore at Maharahara.

Rep. of Geol. Explor., No. 10, 1877; parts of pp. x–xi, 67–94, especially pp. 68, 69, 74–76, 77, 80, 91; No. 18, 1887, p. 34; No. 19, 1888, pp. xxxii–xxxiii, 6–9; No. 20, 1890, pp. xxiv–xxvii; No. 21, 1892, pp. xxvi–xxviii; No. 22, 1894, pp. xxxiv–xxxv, 2–6.

Parl. Paper C.–11, 1896, pp. 47–49 (bound in Mines Rep.).

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914, part of pp. 131–35, 162–70. (2nd ed., 1915.) 10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, p. 30 (J. Henderson).

59. WEBER COUNTY.

The small county of Weber does not occupy a prominent place in geological literature, but it has received some attention from oil-geologists, notably J. Wanner, of Bonn, who reported to a British syndicate a few years ago on the oil possibilities of the district east and west of Weber. The surface of the county is largely occupied by Miocene or Pliocene sandstones, claystones, and allied rocks. Probable Cretaceous chalky limestone and glauconitic sandstone are present east of Weber, and similar rocks also occur in the Wimbledon district. Slightly or moderately calcareous claystones have a great development, and two bores in search of oil in the Waipatiki district west of Weber passed through thousands of feet of this kind of rock. A greensand bed in one of the bores was almost the only marked variation from the claystone type.

In the extreme west of Weber on Oparae Hill there are two bands of gritty limestone. These were described under the heading of "Dannevirke County." Similar rock probably occurs on or near the next hill-top to the south, but beyond this the Puketoi Range passes out of Weber County.

Summary of Lime Resources and of Means of Transport.

Weber County is not well endowed with high-grade limestone, and at the present time has rather poor roads and no railway, so that it may be many years before lime can be conveniently distributed in the county. The nearest outside limestone deposits are in Dannevirke County a few miles north-north-west of Weber (see p. 142), at Cape Turnagain in Patangata County, in the valley of the Aohanga River, and possibly in the Akitio Valley also.

Literature.

The chief references to Weber County in the literature consulted are—

Trans. N.Z. Inst., vol. 26, 1894, pp. 392–96 (Hill).

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2 (Mines Report), 1914, part of pp. 131–35. (2nd ed., 1915.) 9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, p. 103.

60. MANAWATU COUNTY.

Manawatu County is almost if not entirely covered by the alluvial deposits of the Rangitikei and Manawatu rivers, except along the coast-line, where blown sands, as elsewhere in the Wanganui Bight, are well developed. It is part of the Wanganui Plain, and presumably the superficial deposits are everywhere underlain by the Pliocene beds that are seen in the counties to the north. There may possibly be some calcareous sand along the coast, but otherwise Manawatu has no internal lime resources, and must obtain its lime from other parts of New Zealand. Suggested sources are

Mauriceville, Takapau district, and northern Nelson. The Wellington–Auckland Railway is near the county boundary for some miles, but enters it only at the north-east corner near Feilding. A branch line extends from Longburn Junction to Foxton, the small port near the mouth of the Manawatu. Small vessels may possibly be able to enter the mouth of the Rangitikei also. Mauriceville and Takapau are both well within a hundred miles of all railway-stations in or near Manawatu County.

Literature.

Owing to its general flatness, and the consequent absence of outcrops of hard rocks, Manawatu County is in the happy position of being practically without any geological literature. Such as there is refers to the rivers and the sand-dunes. The observed references are—

Rep. Geol. Explor., No. 18, 1887, map opposite p. 32 and p. 58.

Trans. N.Z. Inst., vol. 14, 1882, pp. 89–94 (W. T. L. Travers).

Cockayne, L.: "Report on the Sand-dunes of New Zealand," Parl. Paper C.–13, 1909; "Report on the Dune Areas of New Zealand," Parl. Paper C.–13, 1911 (see p. 5, &c.).

61. Kairanga County.

Most of the small county of Kairanga, with the thriving town of Palmerston North as its commercial centre, is in the Wanganui Plain, and is covered by the alluvial deposits of the Manawatu River. The Tararua Range forms its eastern boundary. This range is a continuation of the Ruahine Range, from which it is separated only by the gorge in which the Manawatu River flows, and is composed of the same kinds of rocks—namely, old Mesozoic argillites and greywackes. Near the western edge of the Tararua Range, Pliocene conglomerates, sands, and claystones with some very poor lignite are seen on the banks of the Manawatu River and at one or two other places.

The following analysis represents a sample attributed to Palmerston North, but which must necessarily have been obtained some distance from that town:—

Water expelled at 100° C.	1·69
Loss on ignition	1·26
Silica and matter insoluble in dilute acid	7·08
Alumina and iron oxide	1·90
Lime carbonate	85·90
Magnesia	1·80
Alkalies and undetermined	0·37
	100·00

Reference.—Forwarded by Mr. C. A. Philips, Palmerston North. Aston, B. C.: 11th Ann. Rep. Dept. Agric., App. I, Chem. Division, 1903, pp. 16, 22. Analyst's number, D 10.

So far as is known Kairanga County, notwithstanding the analysis quoted above, has no limestone, but is rich enough to pay for the limestone it needs. This can be obtained by rail either from the Mauriceville district or from the limestone areas north of Dannevirke. It may also be possible to obtain some limestone from the east end of the Manawatu Gorge, either on the north side of the gorge or on the south side (Ballance district).

It is hardly necessary to draw attention to the excellent railway and road communications of fortunate Kairanga County. It is equally fortunate in affording little or no scope for the geologist, who has therefore found no occasion for writing long reports on its geology. The chief references in geological literature are—

Rep. of Geol. Explor., No. 18, 1887, map opposite p. 32.

Part of Parl. Paper C.-10, 1901 (bound in Mines Rep.), pp. 25–26 ("Coal at Fitzherbert").

Trans. N.Z. Inst., vol. 2, 1870, pp. 346, 358, &c. (Crawford); vol. 27, 1895, pp. 476–77 (Hill); vol. 31, 1899, pp. 551–54 (J. Marchbanks and J. Hector, on artesian wells at Longburn).

62. Pahiatua County.

In the west of Pahiatua County is the Tararua Range, composed of old Mesozoic argillites and greywackes. This is flanked on the east by Pliocene and Miocene conglomerates, sandstone, claystones, and limestones, which near the mountains are fault-involved, and dip at high angles. Eastward there is low country, in which the Tertiary rocks are more or less masked by ancient or modern river-gravels, &c. Farther east is decidedly hilly country, where calcareous claystone and fine sandstone in places are the prevailing rocks. In the eastern part of the county the Puketoi Range rises to a height of over 2,000 ft. It has a rounded fairly even crest, and the topography as seen from a distance suggests that it is composed of similar rocks to those of the Ruahine Range; but, so far as known, these rocks, though present, are of minor importance, and far the greater part of the range is formed of Tertiary rocks. According to McKay (1877 report, p. 76) limestone covers a great part of the range; and this has been confirmed by inquiry from a landowner in the district. South of the Manawatu Gorge limestone of moderately good quality occurs in the Ballance district, apparently towards the foot of the Tararua Range, and thus in continuation of that found to the north near the Gorge Railway-station.

Shelly limestone is seen at the Makakahi Bridge, four miles and a half south of Pahiatua, and forms part of the hilly country to the east. Westward of this locality similar limestone is exposed in the main valley of the Mangahao River, and in one or more of the streams draining the Ruahine Range to the west. The subjoined section (fig. 4) given by McKay (1892 report, p. 29) illustrates the geology of this part of Pahiatua County.

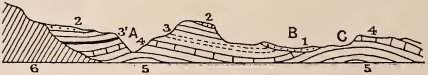

Fig. 4.—Section from North Slope, Tararua Range, to Makakahi Bridge, Pahiatua County.

A. Mangahao River. B. Mangatainoko River. C. Makakahi River.

1. Alluvial. 2. High-level gravels. 3. Pumice sands. 3^1. Pumice sands with lignite. 4. Shelly limestone. 5. Blue sandy clays (fossiliferous). 6. Old rocks (Mesozoic) of the Tararua Range.

Note.—A great fault, not indicated in the section, probably separates the Tertiary rocks (3–5) from the Mesozoic rocks (6) of the Tararua Range.

Shell limestone occurs near the junction of the Mangatainoka and Manawatu rivers, and extends as a low range into Dannevirke County (see p. 142). Limestone occurs in the Makuri district at the foot of the Puketoi Range, but no particulars concerning it have been obtained, except in so far as the statements by Aston quoted below refer to the locality.

In the *Journal of Agriculture*, vol. 11, No. 5, 1915, pp. 406–7, B. C. Aston describes some limestone deposits in Pahiatua County as follows:—

"*Pahiatua and Makuri Gorge Deposits.*

"In the above districts there is a plethora of valuable limestone, some of which is high grade and of exceptional friability. Unfortunately, the deposits are some distance from the railway-line. Thus at the Konini waterworks there is a deposit of calcareous sinter or travertine containing 91 to 96 per cent. of carbonate of lime in a form which would be reduced to a fine powder with the greatest ease. In the same locality are cliffs of hard limestone similar to that of Mauriceville, of 91 per cent. carbonate of lime. At Ballance there is another similar deposit of hard stone containing 94·3 per cent. carbonate; but, best of all, at the Pahiatua end of the Makuri Gorge is a soft pure-white calcareous deposit which contains 93·3 per cent. carbonate — that is, it is practically as rich as Mauriceville stone, and has the additional merit of being so soft that it may be rubbed to a fine powder between the fingers.

"I am much indebted to Mr. W. Wakeman, of Pahiatua, for great assistance rendered me in obtaining samples and locating suitable deposits in this district."

Mr. Aston also gives (p. 410) the following analyses of various samples obtained within a few miles of Pahiatua, and of a sample of "soft" limestone from Makuri Gorge:—

Lab. No.	Locality.	Insoluble Matter (Sand, &c.).	Alumina and Iron Oxides.	Calcium Carbonate ($CaCO_3$).	Magnesium Carbonate, &c.	Approximate Yield of Quicklime (CaO) in Calcined Limestone.	Remarks.
		Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	
G 501	No. 2 pit, Konini Road	6·5	1·6	91·0	0·9	85	Fairly hard stone.
502*	Above Pahiatua waterworks, Konini	7·4	1·5	90·0	1·1	83	Soft secondary calcareous sinter, contained 21·7 per cent. water.
503	Makuri Gorge . .	4·6	1·3	93·3	0·8	89	Soft limestone.
444	Konini gravel-pit . .	21·4	2·3	70·7	5·6	58	Shelly conglomerate.
445	Near Konini waterworks	13·0	2·3	83·3	1·4	74	Shelly conglomerate.
446	Near Konini waterworks	0·7	2·7	96·1	0·5	93	Fairly soft stone.
447	Between Mangatainoka and Pahiatua	22·5	2·6	72·4	2·5	59	Hard stone.

* Analysis made on the sample dried to constant weight on water-bath.

The following table gives analyses of five samples of limestone from the Ballance district:—

	(1)	(2)	(3)	(4)	(5)
Silica	6·71	10·81	9·08	3·45	3·6
Alumina and iron oxide	1·87	3·21	3·01	0·96	1·4
Lime	49·20	46·45	47·95	51·82	(52·8)
Magnesia	1·19	0·85	0·83	0·69	. .
Phosphoric anhydride	0·16	0·15	0·15	0·24	. .
Carbon dioxide	38·66	36·50	37·68	40·71	(41·5)
Water and organic matter	1·93	1·45	1·30	1·75	. .
Alkalies and undetermined	0·28	0·58	. .	0·38	0·7
	100·00	100·00	100·00	100·00	100·0
Carbonate of lime, per cent. (by addition of lime and carbon dioxide)	87·86	82·95	85·63	92·53	94·3
Lime in calcined stone (per cent.)	82·81	74·86	78·59	90·08	90

References.—No. 1 (marked "Hays"), No. 2 ("Cornelius"), No. 3 ("Matthews"), and No. 4 ("Hays"), all forwarded by the Chairman, Farmers' Union, Ballance. Dom. Lab. 46th Ann. Rep., 1913, p. 15. Lab. Nos. C 945/1–4. "Of these samples, No. 4 is the best, giving a lime well suited for building or agricultural purposes. The others are of fair quality only."

(5) Aston, B. C.: Jour. Agric., vol. 11, No. 5, Nov., 1915, p. 410. Analyst's number, G 504. "Very hard stone."

The analyses of four samples of limestone attributed to Pahiatua are given below:—

	(1)	(2)	(3)	(4)
Matter insoluble in acid	18·21	1·30	14·16	3·64
Alumina	2·22	0·32	1·90	1·84
Iron oxides	Traces			
Calcium carbonate	74·97	96·80	78·83	89·46
Magnesium carbonate, &c.	2·96	1·58	5·11	2·25
Water	1·64	..	..	..
	100·00	100·00	100·00	97·19
Quicklime in calcined stone, per cent. (Aston)	..	97	..	82

References.—(1) Calcareous freestone (or arenaceous limestone) from Pahiatua, forwarded by R. Parker. Col. Mus. and Lab. 23rd Ann. Rep., 1889, p. 54. Lab. No. 4863.

(2) From Pahiatua, forwarded by W. Wakeman. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. No. E 490. "A first-class agricultural limestone."

(3) From Pahiatua, forwarded by H. S. Morrison. Same publication and page as No. 2. Lab. No. E 673. "Rather poor stone."

(4) From Pahiatua. Aston, B. C., Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 239. Analyst's number, K 233. Date, 1909.

Summary of Limestone Resources and of Means of Transport.

The limestones of the Ballance district appear to be of fair quality, but the samples of which analyses are quoted may not have been representative, and therefore resampling by an experienced person on a more extensive scale is advisable. The limestone on top of the Puketoi Range is not in a suitable position for distribution. According to B. C. Aston the limestones at Konini (near Pahiatua) and at Makuri Gorge are in part of high quality. His enthusiastic description of them is quoted above. Pahiatua County is probably fairly well supplied with limestone suitable for being crushed and spread on the land without previous calcination, but may not possess much high-grade stone adapted for being calcined. Being traversed by the Napier–Woodville–Wellington Railway, the lowlands of the county can easily import lime from Mauriceville to the south, or from Takapau, &c., to the north.

Literature.

The chief references to the geology of Pahiatua County are—

Rep. of Geol. Explor., No. 10, 1877, pp. 74, 75, 76, 80, and map opposite p. 88, &c.; No. 21, 1892, pp. 28–30.

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2 (Mines Rep.), 1914, part of pp. 131–35. (2nd ed., 1915.)

63. AKITIO COUNTY.

Late Mesozoic (Cretaceous) and perhaps also Middle Mesozoic sandstones, claystones, and allied rocks are well developed along the coast of Akitio County. Possibly Middle or even Early Mesozoic rocks occur at the head of the Mataikona River, where Castlepoint, Eketahuna, and Akitio counties meet. Elsewhere, from a few miles inland to the crest of the Puketoi Range, which forms the western boundary of the county, Miocene and Pliocene sandstones, claystones, and limestones are the prevailing rocks. Limestone is well developed in the gorge of the Aohanga River, six miles inland (by road) from Aohanga. Near a hill-top about a mile and a half north-east of Pongaroa grey-blue limestone of good quality is quarried for roadmaking by the County Council. It is delivered by aerial tram to a rock-breaking plant. A few miles south of Pongaroa (? near Rakaunui) the County Council has another quarry in shell-limestone, similarly equipped. As previously mentioned, limestone caps the Puketoi Range, and is found also in the extreme south-west of the county in the headwaters of the Tiraumea Stream. (See under Eketahuna, p. 153.)

A sample of limestone from Akitio, forwarded in 1911 by F. Handyside to the Dominion Laboratory, yielded on analysis 97·55 per cent. of calcium carbonate (Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 567). This seemingly indicates the presence of very high-grade limestone in the Akitio district, but, as it is perhaps unnecessary to say, particulars concerning the locality and the quantity of stone available, together with further analyses of representative samples, are required before a definite opinion can be expressed. The following analyses of samples from Pongaroa indicate that fairly good limestone is obtainable in that district:—

	(1)	(2)
Matter insoluble in acid, &c.	8·00	3·32
Alumina and iron oxides	3·58	1·48
Calcium carbonate ($CaCO_3$)	84·59	94·60
Magnesium carbonate, &c.	1·26	0·70
Calcium oxide (CaO) combined as silicate, &c.	1·89	..
Water	0·68	..
	100·00	100·10
Quicklime (CaO) in calcined stone (per cent.)	80·17	92

References.—(1) Forwarded by Mr. John Ryan. Col. Lab. 39th Ann. Rep., 1906, pp. 9–10, Lab. No. 142. The sample was a small one, consisting of white stone (calcite) and light-yellow limestone. It was therefore not of a representative character. The original analysis has not been exactly quoted. It gives—Lime, 49·26 per cent.; magnesia, 0·60 per cent.; and carbon dioxide, 37·88 per cent.

(2) Dom. Lab. 43rd Ann. Rep., 1910, p. 52. Lab. No. L 850. There is a slight error in the analysis as quoted. Probably "magnesium carbonate, &c.," should read "0·60" instead "of 0·70."

Summary of Limestone Resources and of Means of Transport.

From the information available it is not possible to express a definite opinion concerning the limestone resources of Akitio County. Before this can be done considerable exploration is necessary. Limestone is found in the lower part of the Aohanga River, on the summit of the Puketoi Range, and elsewhere in more or less remote localities. In the neighbourhood of Pongaroa there is a little good limestone in accessible positions, but this is needed for roadmaking as well as for agriculture.

At present Akitio County has no railway, and somewhat poor roads. The mouths of the Akitio and Aohanga rivers can be entered by small craft. A loop-line railway which will leave the Wellington–Napier Railway at Masterton or to the north, passing through Pongaroa, Weber, &c., and joining the main line again north of Dannevirke, is projected.

Literature.

Various references to the geology of Akitio County are given below. Some of these are of very little importance.

Trans. N.Z. Inst., vol. 1, 2nd ed., 1875, p. 320 (Crawford); vol. 15, 1883, p. 379 (barite mentioned by Cox); vol. 39, 1906, part of pp. 509–20 (Hill).

Rep. of Geol. Explor., No. 9, 1877, p. 50; No. 12, 1879, p. 72; No. 19, 1888, part of pp. 20–24.

Parl. Paper C.–16, 1910 (Morgan).

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2 (Mines Rep.), 1914, part of pp. 131–35. (2nd ed., 1915.)

64. Horowhenua County.

The Tararua Range forms the eastern boundary and the sea the western boundary of Horowhenua County. In the main the county is an alluvial plain, in places swampy, built by the gravels of the Manawatu, Ohau, Otaki, and Waikanae rivers. Near Otaki one or two hills of greywacke have been isolated from the Tararua Range by the action of the Otaki River. In this district also Pleistocene sandstone, probably of wind-blown origin, covers a considerable area. Along the coast-line are somewhat extensive sand-dunes.

Horowhenua County has practically no lime resources of its own, although limestone or marble is said to occur in the Otaki Valley nine miles from the railway-line (Trans. N.Z. Inst., vol. 21, p. 487). It is traversed by the Main Trunk Railway, and can obtain lime by rail from Mauriceville, Ormondville, Takapau, or other limestone districts on the eastern side of the Tararua-Ruahine Range. From Mauriceville to Tokomaru, in the north of the county, by rail is about sixty-five miles; to Waikanae, in the south, 104 miles. From Ormondville the distances are eight miles less; from Takapau perhaps greater by a mile. The importation of lime by sea from north-west Nelson to the ports of Wellington and Foxton is also feasible.

Literature.

Among the references to the geology of Horowhenua County are—

Trans. N.Z. Inst., vol. 2, 1870, p. 347 (Crawford); vol. 10, 1878, pp. 478, 479 (Crawford); vol. 14, 1882, pp. 89–94 (Travers, on sand-dunes); vol. 43, 1911, pp. 496–520 (G. L. Adkin); vol. 44, 1912, pp. 308–16 (Adkin).

Rep. of Geol. Explor., No. 22, 1894, pp. 1–2. Dr. L. Cockayne's reports of 1909 and 1911 on sand-dunes, with some of the literature listed therein, may also be consulted (for titles see Manawatu County).

65. Eketahuna County.

The western boundary of Eketahuna County is the Tararua Range, composed mainly of old Mesozoic argillites and greywackes. Calcareous diabasic tuff and limestone or marble may also be present. A little to the east of the road from Masterton to Woodville, at a point four or five miles south-west of the town of Eketahuna, shattered limestone or marble outcrops on the left or south side of a small stream coming from the east. It occurs as a nearly horizontal bed, 6 ft. to 10 ft. thick, on a ridge 40 ft. to 60 ft. above the stream-bed, and is described by McKay (1888 report, pp. 5–6, 18–20) as a highly ornamental stone. The following analysis shows that it is of fairly good quality from the agricultural point of view:—

Carbonate of lime	90·86
Carbonate of magnesia	2·79
Alumina	2·80
Iron oxides	Traces
Silica	3·41
Water	0·14
	100·00

Reference.—Grey limestone from outcrop described above, forwarded by Mr. S. Bacon (?). Rep. of Geol. Explor., No. 19, 1888, pp. 5–6 and 18–20. See also Col. Mus. and Lab. 23rd Ann. Rep., 1889, p. 78. Lab. No. 4690. Previously Mr. Bacon had forwarded a sample of earthy argillaceous limestone which contained only 62·75 per cent. of carbonate of lime. (See p. 18 of Geol. Rep., and pp. 53 and 59 of Lab. Rep. cited. Lab. No. 4674.)

The marble is associated with diabasic tuffs in a belt of Mesozoic rocks, which stretches eastward from this locality to a point in the Tiraumea Valley north of Alfredton. It is flanked to the north and south by Tertiary sandstones and claystones, capped in places by limestone. Mesozoic rocks are again seen as a small patch in the Upper Tiraumea Valley, eight miles or so eastward of Alfredton. They are overlain by sandstone with lignite-seams, calcareous claystone, and limestone. These rocks are probably of Miocene age. The limestone occurs in patches east of the Upper Tiraumea and more continuously towards its headwaters, which are in Akitio County. According to Bell (1909 report, p. 3) it is generally impure, and either sandy or clayey. The following analyses show the composition of samples collected by him in the Upper Tiraumea district, from Maire Creek and Tiraumea Falls:—

	(1)	(2)
Silica (SiO_2)	28·20	33·20
Alumina (Al_2O_3)	5·16	4·97
Iron oxide (Fe_2O_3)	1·64	1·88
Lime (CaO)	35·25	30·12
Magnesia (MgO)	0·74	0·76
Carbonic anhydride (CO_2)	28·20	24·10
Moisture and organic matter	0·32	3·72
Alkalies and undetermined	0·49	1·25
	100·00	100·00
Carbonate of lime, per cent. (by addition of CaO and CO_2)	63·45	54·22

References.—3rd Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1909, p. 3; and Dom. Lab. 42nd Ann. Rep., 1909, p. 21. No. 1 is from Maire Creek, and No. 2 from Tiraumea Falls. Lab. Nos. 1960/1, 2.

The Tertiary limestone found near Eketahuna is represented by the following analysis of a sample of shelly limestone from No. 1 Special-settlement Block, Section 68, Newman, forwarded to the Colonial Laboratory in or about 1892 by Mr. James B. Tarr, of Karori. It contained a considerable quantity of sandy matter.

Carbonate of lime	59·03
Carbonate of magnesia	2·78
Iron oxide and alumina (soluble in acid used)	1·69
Siliceous matters	36·24
Water	0·26
	100·00

Reference.—Col. Mus. and Lab. 27th Ann. Rep., 1893, pp. 23–24. Lab. No. 5985.

Summary of Limestone Resources and of Means of Transport.

Eketahuna County probably possesses considerable limestone resources, but prospecting is necessary in order to ascertain exactly what these are. Those parts of the county near the Wellington–Napier Railway-line are well situated to receive lime from the Mauriceville district, which is only a few miles outside the county. The importation of lime or crushed limestone from any of the counties bordering the railway to the north is also quite feasible. From Poukawa southward all railway-stations are within a hundred miles of Eketahuna.

Literature.

Among the geological references to Eketahuna County are—

Rep. of Geol. Explor., No. 10, 1877, p. 74, map opposite p. 88, &c.; No. 19, 188, pp. xxxiii, 5–6, 18–20.

Trans. N.Z. Inst., vol. 13, 1881, p. 437 (coal near Eketahuna); vol. 21, 1889, pp. 486–87 (McKay).

Parl. Paper C.–11, 1896 (bound in Mines Rep.), pp. 49–51 (McKay).

3rd Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1909, p. 3 (J. M. Bell). 8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2 (Mines Rep.), 1914, part of pp. 131–35 (2nd ed., 1915).

66. MAURICEVILLE COUNTY.

Mauriceville County lies immediately south of Eketahuna County, and has the same general geology, but the only locality where Mesozoic rocks are known to occur away from the Tararua Mountains is a little north-west of Mauriceville Railway-station (McKay, 1896). West and east of the valley through which the Napier–Wairarapa–Wellington Railway runs there is a good deal of hilly country, mainly composed of Tertiary sandstone, claystone, and limestone. Almost the only locality where the limestone has received much attention is that west of the railway-line, close to Mauriceville Railway-station, where it has been extensively quarried for agricultural purposes. The rock here is friable, and presents the characters of a limestone formed under littoral (near-shore) conditions. It is thus described by Henderson: "The rock is made up of shell-fragments and contains a few particles of greywacke, while towards the top a layer of calcareous conglomerate perhaps 6 ft. in thickness is interbedded. The whole is overlain by blue fossiliferous sandstone, but contact with the underlying strata, which also consist of sandstone, was not observed. Where worked the limestone strikes about 170° and dips eastward at a very steep angle, its thickness here being about 300 ft. Southward the limestone is decidedly thinner, being replaced by conglomerate, of which a section is well exposed in a cutting on the road to Mauriceville West, 20 chains from the railway-station. A similar condition is reported to obtain to the northward, but the writer did not explore the district in this direction. The deposit contains a very large tonnage of high-grade limestone, and is admirably situated for cheap exploitation. With a more up-to-date method of quarrying, and modern drying-machinery, ground limestone could be produced at a cost materially lower than at present."

B. C. Aston describes the Mauriceville limestone deposit in the following terms, which are rather too enthusiastic to meet the approval of the hard-headed, cold-blooded, mining engineer, who, as a rule, has been too often disappointed to have much of his youthful enthusiasm left, and who would point to Dr. Henderson's remarks, and the various analyses here quoted, as evidence that the average grade of the stone does not exceed 90 per cent., and that it varies in composition in much the same way as other limestones:—

"Mauriceville Deposit: Those who inspect the Mauriceville Lime Company's works are impressed with the wonderful natural facilities that exist for working the immense deposit of high-grade limestone which occurs there. This is an isolated hill, rising from the plain to a height of about 200 ft., composed of almost pure limestone. There is practically no stripping to do. It is an easy quarry to work, and the quality of limestone is high (about 95 per cent.). On quarrying, much (about one-third) of the material, which is remarkably uniform in composition, separates as powder, and could be successfully used for application to the land at once without further reduction.

At the foot of the hill, on a level with the kilns, is the railway-station, whence the privilege of 100 miles free carriage of treated limestone is allowed. What is required at Mauriceville is better machinery for reduction of the stone to a fine powder, and this improvement will, I hope, shortly be effected."

The following analyses of limestone from or near Mauriceville may be quoted :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Matter insoluble in acid, silica, &c.	2·71	..	..	4·22	3·19	8·64	3·79	10·31	..
Alumina	10·00	..	..	2·41	2·34	2·16	3·14	2·63	..
Iron oxides	..	..	..						
Calcium carbonate	84·19	93·14	91·96	90·23	91·98	85·93	89·71	84·16	92·30
Magnesium carbonate, &c.	2·96	..	..	2·87	2·18	2·98	3·16	2·69	..
Water	0·14	..	..	0·27	0·31	0·29	0·20	0·21	..
	100·00	..	..	100·00	100·00	100·00	100·00	100·00	..
Quicklime in calcined stone, per cent. (Aston and others)	78	88·4	86·7	83	87	79	83	77	87

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Matter insoluble in acid, silica, &c.	26·0	3·82	1·88	1·98	13·81	3·6	0·6	4·7
Alumina	1·0	4·78	2·86	1·16	2·72	1·8	0·6	1·7
Iron oxides								
Calcium carbonate	71·5	90·63	94·41	91·26	80·16	92·8	98·7	93·3
Magnesium carbonate, &c.	..	0·32	0·25	1·95	3·31	1·8	0·1	0·3
Water	1·5	0.45	0·60	..	..	..	..	..
	100·0	100·00	100·00	96·35	100·00	100·0	100·0	100·0
Quicklime in calcined stone, per cent. (Aston and others)	59·4	85	91	85	69	88	98	88

References.—(1) Pale buff-coloured shelly limestone, very close-grained, from Mauriceville, forwarded by W. H. Kells. Col. Mus. and Lab. 22nd Ann. Rep., 1887, p. 41. Lab. No. 4343. " A capital building-stone." The analyst reports a trace of manganese.

(2) (3) Limestone from Mauriceville, forwarded by T. F. Brenchelly (? Brenchley), through the Mines Department. Col. Mus. and Lab. 23rd Ann. Rep., 1889, p. 56. Lab. Nos. 4928/1, 2. " Both specimens will do well for lime."

(4) Limestone, one mile from Brook Quarry, Mauriceville, forwarded by William Maddock. Col. Mus. and Lab. 26th Ann. Rep., 1892, p. 28.

(5) Porous limestone (" travertine ") from Mauriceville, forwarded by T. F. Brenchley (see also Nos. 2 and 3). Col. Lab. 30th Ann. Rep., 1897, p. 11. Lab. No. 7272. It is not probable that this sample represented a travertine. The analyst (W. S. Skey) states that it occurs as a coarse sand mixed with small nodules, which could be easily broken down by passing them under a fluted roller. The application of " this naturally comminuted limestone " without calcination to the soil is recommended.

(6) Buff-coloured, (7) red, and (8) more or less bluish-slaty-coloured shelly limestones from Mauriceville, forwarded by F. Broderson. Col. Lab. 31st Ann. Rep., 1898, p. 12. Lab. Nos. 7808/1, 2, 3.

(9) From Mauriceville, forwarded by Sir James Hector. Col. Lab. 36th Ann. Rep., 1903, p. 8. Lab. No. 9393.

(10) Impure limestone from Mauriceville, forwarded by F. W. H. Kummer. Col. Lab. 37th Ann. Rep., 1904, p. 8. Lab. No. 9447.

(11) (12) From Mauriceville. Dom. Lab. 43rd Ann. Rep., 1910, p. 52. Lab. Nos. L 479 and L 480.

(13) From Mauriceville. Aston, B. C., Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 239. Analyst's No. K 1107. Date, 1909.

(14) From Mangamahoe (north of Mauriceville). Same reference as (13). Analyst's No. G 279. Date, 1915.

(15) (17) Kiln-dried stone, Mauriceville. B. C. Aston, article previously cited, p. 410. Analyst's Nos. G 370 and G 436.

(16) Calcareous sinter, Mauriceville. Same reference as No. 15. Analyst's No. G 372.

The deposit near Mauriceville Railway-station seems well suited for the production of pulverized limestone, and is sufficiently pure also to make good quicklime. The material from the quarry that is too fine to be calcined is sold at a low price.

McKay mentions that above the impure lignite outcrops north of Mauriceville Railway-station, on the west side of the Kopuaranga, are sandy clays followed by impure shelly limestone, which passes upward into shelly limestone of better quality.

Summary of Limestone Resources and of Means of Transport.

In the Mauriceville limestone Mauriceville County has at least one good deposit conveniently situated. This alone will supply for many years the needs not only of the county, but also of extensive districts north and south of Mauriceville Railway-station.

From B. C. Aston's analyses (Nos. 15 and 17 of table) it appears that the kiln-dried stone at Mauriceville contains 93 per cent. of carbonate of lime. The percentage of moisture in the rock is not given, nor can it be ascertained from the numerous other analyses quoted, for these evidently represent air-dried samples. Again, no analysis of the fine material, which does not go to the kiln, is available. So far as can be judged from the incomplete data at hand, the carbonate-of-lime content of the Mauriceville deposit as a whole is about 90 per cent. Systematic sampling of the quarry-face is highly advisable, for the numerous grab or "empirical" samples (see Chapter I, p. 27) for which analyses have been made cannot be accepted as wholly representative.

The county is traversed by the Wellington–Wairarapa–Napier Railway, and the area east of the Tararua Range has good roads. Transport facilities are therefore good.

Literature.

The chief references to the geology of Mauriceville County that have been noted are—

Trans. N.Z. Inst., vol. 2, 1870, p. 343 (Crawford).
Rep. of Geol. Explor., No. 19, 1888, p. 4 (source of Ruamahanga).
Parl. Paper C.–11, 1896 (bound in Mines Rep.), p. 51.
10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, p. 30 (Henderson).

67. CASTLEPOINT COUNTY.

So far as known Castlepoint County consists mainly of claystones, sandstones, and allied rocks of Cretaceous or, in part, even of Jurassic age. On the western boundary small areas of Pliocene or Miocene rocks are to be found. Although some Miocene fossils are stated by J. C. Crawford and McKay to have been found on the summit of the hill known as the Tinui (or Tenui) Taipo, the main mass of that hill and similar hills in the neighbourhood is apparently unfossiliferous sandstone suspected to be of pre-Tertiary age.

A small patch of Tertiary argillaceous sandstone and shelly limestone forms the greater part of the headland known as Castle Point.

Argillaceous sandy limestone is said to be found over a considerable extent of country in the southern part of the county, on the estate formerly owned by the Rev. J. C. Andrew ("Ica"). An analysis of a sample obtained about June, 1888. from the neighbourhood of Ica homestead by Park is as follows :—

Carbonate of lime	76·41
Carbonate of magnesia	2·84
Alumina and iron soluble in acid	0·61
Alumina as part of clay	4·19
Silica as part of clay and sand	14·21
Water	1·74
	100·00

References.—Rep. of Geol. Explor. during 1887–88, No. 19, 1888, p. 24; and Col. Mus. and Lab. 23rd Ann. Rep., 1889, p. 56. Lab. No. 4946.

Summary of Limestone Resources and of Means of Transport.

Castlepoint County apparently has few or no high-grade limestone deposits. Since it is mainly a pastoral district the want of convenient sources of lime is not likely to be seriously felt for many years. The county has no railway, and at the present time the roads are poor. There is no port, but there are one or two landing-places and boat-harbours on the coast, by means of which wool is shipped and station stores, &c., are landed.

Literature.

The chief references to the geology of Castlepoint County observed in the literature consulted are—

Rep. of Geol. Explor., No. 9, 1877, pp. 50, 51, 52; No. 10, 1877, pp. 73, 89, 90; No. 11, 1878, pp. 20, 24; No. 16, 1884, p. 72; No. 19, 1888, part of pp. 20–24.

Parl. Paper C.–9, 1899 (bound in Mines Rep.), pp. 33–36. Parl. Paper C.–16, 1910, part of (Morgan).

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914, part of pp. 131–35. (2nd ed., 1915.)

68. MASTERTON COUNTY.

A section from west to east through Masterton County shows old Mesozoic rocks forming the Tararua Range. At the eastern base of the range it will probably show a belt of Tertiary sandstones, claystones, and perhaps limestones, more or less fault-involved. East of this is the upper part of the Ruamahanga or Wairarapa Plain, covered by river-gravels. Some miles east of Masterton a belt of Pliocene and Miocene calcareous claystones and shelly limestones appears, and continues up the Mangapakeha* Valley to Blairlogie or Awatoetoe, where old-looking claystones and the sandstones forming the Taipo Range come in to the east of a great fault with a northerly strike. A good many miles to the southward igneous rocks are well developed in the Brancepeth district. So far as known the coastal belt is composed of Cretaceous rocks, principally sandstones.

Near Taueru a yellowish shelly limestone of considerable thickness underlain by blue calcareous claystone is well developed on the north side of the road, and is favourably situated for quarrying. The rock is reported to contain over 90 per cent. of carbonate of lime, and its quality is almost certainly good, but no analyses are available. East of Carswell's, and especially on Awatoetoe sheep-station, south of Kerosene Ridge, bands of shelly pebbly limestone appear in the calcareous claystones over a considerable extent of country, but in many places are calcareous conglomerates rather than limestones. At the head of Middle Division Creek a thick bed of shelly conglomerate is seen at the base of the mudstones. The strike is north-north-east, and the dip about 45° to the westward. South of Cameron's Look-out the shelly conglomerate seems to die out, but boulders are seen along Kerosene Ridge near the Blairlogie gas-spring, and north of the Mangapakeha Stream, where shelly rock outcrops towards the head of a small stream opposite Mr. Cameron's house. The shelly pebbly limestone or shell conglomerate is a most typical littoral deposit, comparable with the Manawatu Gorge limestone (see p. 144).

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* This name is spelt in various ways.

The following analyses of calcareous rocks from Masterton County may be quoted :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Matter insoluble in acid, &c. ..	47·70	37·68	21·55	1·16	18·21	22·26	15·44
Alumina and iron oxides	6·50	4·05	4·00	0·40	0·10	2·60	1·44
Manganese oxide	0·50	..	..	..	..	..	..
Calcium carbonate	42·50	56·48	72·92	95·39	80·17	74·39	81·11
Magnesium carbonate, &c. ..	1·50	1·79	1·53	0·68	0·49	0·03	0·65
Alkalies and undetermined ..	1·30	..	..	2·37	1·03	0·72	1·36
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Quicklime in calcined stone, per cent. (Aston)	..	42	60	96	71	63	72

References.—(1) Arenaceous limestone (or, rather, calcareous sandstone) from Bushcroft, Masterton, forwarded by E. L. Holmwood. Col. Lab. 35th Ann. Rep., 1902, p. 9. Lab. No. 9198.

(2) (3) From Awatoetoe, forwarded by H. Morrison. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. Nos. D 1026/1, 2. Probably these analyses represent the impure shelly pebbly limestone or calcareous conglomerate mentioned above.

(4) (5) (6) (7) From Masterton (district). Aston, B. C., Jour. Agric., vol. 11, No. 3, Sept., 1915, p. 239. Analyst's Nos. J 549 to 552. Date, 1908.

Summary of Limestone Resources and of Means of Transport.

The Taueru limestone will ultimately be of great value to the Masterton district, but at present it is not near a railway, and material from it cannot be conveniently distributed. Lime or pulverized limestone can conveniently be supplied from Mauriceville to all districts near the Wellington–Napier Railway-line, which traverses Masterton County. The eastern half of the county, from Taueru to the coast, is somewhat out of touch with the railway, and as yet is not well roaded.

Literature.

The chief references to the geology of Masterton County are—

Rep. of Geol. Explor., No. 9, 1877, pp. 51, 52, 53; No. 10, 1877, pp. 73, 89, 90, 91, and map opposite p. 88; No. 11, 1878, part of pp. 14, 24; No. 12, 1879, p. 83; No. 16, 1884, pp. 71–75; No. 18, 1887, pp. 40–42; No. 19, 1888, pp. 20–24; No. 21, 1892, pp. 170, 171 (Wairarapa North and South counties).

Parl. Paper C.–9, 1899 (bound in Mines Rep.), part of pp. 36–43. Parl. Paper C.–16, 1910 (Morgan).

Sollas, W. J., and McKay, Alex.: "The Rocks of Cape Colville Peninsula," vol. 2, 1906, pp. 155–57.

8th Ann. Rep. N.Z. Geol. Surv., part of C.–2 (Mines Rep.), 1914, pp. 131–35. (2nd ed., 1915.)

69. WAIRARAPA SOUTH COUNTY.

The geology and topography of Wairarapa South County are similar to those of Masterton County. Igneous rocks are not so prominent as in the Brancepeth district, but appear in several localities in the eastern part of the county. A belt of old Mesozoic rocks outcrops near Te Wharau, and extends southward into Featherston County. Limestone of supposed Cretaceous age covers two considerable areas in the eastern or coastal district. One of these is near Glenburn (south of Flat Point), where it extends westward for four miles, and, gradually narrowing, northward to the East Coast Road, where the limestone area is still half a mile wide. For two miles north of Glenburn limestone outcrops on the coast. The second limestone area forms a strip several miles long, with a maximum width of one mile, extending from the Kaiwhata River southward along the eastern flank of the coastal range of hills to a point not far north of the East Coast Road. The same belt also extends northward into Masterton County (W. A. McKay, 1899 report, p. 41).

From the Ruamahanga River eastward Tertiary conglomerate, sandstone, and calcareous claystone and limestone are the principal rocks till the Pahaoa Valley is reached. Rocks of similar age also form portions of the country to the west. Limestone similar to the Taueru shelly limestone is prominent in the area west of the Pahaoa River. It forms much of the Maungaraki Range, and in places large outcrops that can be easily worked occur close to roads. Definite information as to the distribution of the limestone is wanting, but according to Alex. McKay a belt extends from Taueru almost continuously to near the shores of Palliser Bay. Four analyses, three of which represent excellent limestones, are quoted below:—

	(1)	(2)	(3)	(4)
Matter insoluble in acid	1·60	0·20	..	28·56
Alumina	0·36	0·30	..	5·12
Iron oxides	0·44	0·10	..	
Calcium carbonate	95·90	95·20	94·10	64·26
Magnesium carbonate, &c.	..	..	..	2·06
Water and organic matter	1·70	4·20	..	..
	100·00	100·00	..	100·00
Quicklime in calcined stone, per cent. (Aston)	95	98	89·9	50

References.—(1) (2) Forwarded by M. Buchanan, Gladstone. Col. Lab. 40th Ann. Rep., 1907, p. 15. Lab. Nos. 711/1, 2.

(3) From Te Wharau, forwarded by Alexander Matheson. Dom. Lab. 43rd Ann. Rep., 1910, p. 12. Lab. No. 256.

(4) From Carterton, forwarded by J. McLean. Dom. Lab. 48th Ann. Rep., 1915, p. 21. Lab. No. E 863.

B. C. Aston mentions a soft or friable limestone in the Gladstone district, a sample of which contained 94 per cent. of calcium carbonate (Ann. Rep. Dept. Agric. for 1916–17, Parl. Paper H.–29, 1917, p. 40). At a later date he gives no less than fifteen analyses of limestone from that district (Jour. Agric., vol. 17, No. 2, Aug., 1918, pp. 99, 100). The percentage of calcium carbonate varies from 67 to 98·6. Six samples are described as soft or friable.

Summary of Limestone Resources and of Means of Transport.

East of the Ruamahanga River, Wairarapa South County appears to have good limestone deposits, but systematic exploration and sampling are needed in order to ascertain what the limestone resources of this area really are. The western part of the county is traversed by the Wellington–Wairarapa Railway, and can conveniently obtain lime from Mauriceville or farther north. No information as to the existence of limestone at the foot of the Tararua Range has been obtained, but possibly the poor limestone represented by analysis No. 4 above came from this quarter. The roads of the county vary from good near the railway to indifferent near the coast.

Literature.

The chief references to the geology of Wairarapa South County in the literature consulted are—

Rep. of Geol. Explor., No. 11, 1878, part of pp. 14–24; No. 19, 1888, parts of pp. xxxiv, 1–6, 58–67.

Parl. Paper C.–9, 1899 (bound in Mines Rep.), part of pp. 36–43 (W. A. McKay).

Sollas, W. J., and McKay, Alex.: "Rocks of Cape Colville Peninsula," vol. 2, 1906, pp. 153–55 (andesite dykes in Cretaceous rocks near Flat Point).

70. FEATHERSTON COUNTY.

In general terms the geology of Featherston County is similar to that of Wairarapa South. In the west the Rimutaka Range, an unbroken continuation of the Tararua Range, is formed of the same types of Mesozoic rocks. East of the mountains is the Wairarapa Plain, partly occupied by shallow lakes. The country east of the plain has a somewhat varied geology. Old Mesozoic rocks are well developed, and form the Haurangi Mountains, which occupy the Cape Palliser Peninsula. Cretaceous rocks, including a limestone similar to the Amuri limestone of the South Island, occur in a belt east of the Haurangi Mountains, whilst from Awhea River to Pahaoa River another belt of old Mesozoic rocks appears on the coast-line, and extends northward into Wairarapa South County. The remainder of the county—that is to say, a central belt extending northward from the east side of Palliser Bay—except for superficial deposits, is occupied mainly by Tertiary sandstones and claystones with more or less limestone. Small areas of Tertiary rocks are also found east of the Haurangi Mountains, near White Rock Station, &c.

Cretaceous limestone occurs in the following localities:—

(1.) North of the Pahaoa River, forming part of a belt of considerable width near the coast. The limestone is interbedded with greensand, which in places is indurated.

(2.) South of the mouth of the Pahaoa River, in a reef extending some distance out to sea. The limestone here is white, close-grained, and flaggy. It is interbedded with layers of greensand from 4 in. to 4 ft. or 5 ft. thick, and dips at about 40° to the westward. Grey and black flints are common in the limestone of this locality.

(3.) At the mouth of the Owhea or Awhea River, south of Te Awaiti. In this locality argillaceous or glauconitic limestone is reported to occur (McKay, 1878 report, p. 21).

(4.) At White Rock Station, seven miles or so north-east of Cape Palliser Lighthouse. The limestone is here exposed on the beach and near the shore-line. According to McKay (1879 report, pp. 79–80) it consists of a considerable thickness of white, flaggy, fine-grained limestone, with thin bands of greensand at intervals. The strike is nearly north and south, and the dip to the west at high angles. Dark-coloured sandy beds and flaggy sandstones underlie. Outcrops may be seen north of White Rock Station on the banks of the Opouawe (or Opouawa) Stream. On a spur to the north great quantities of black flint are reported to exist (McKay, 1878 report, p. 23).

A sample of limestone from White Rock Station was found by B. C. Aston to contain 76·3 per cent. of $CaCO_3$ (Jour. Agri., as cited above, p. 99).

The Tertiary limestone of Featherston County is sometimes called the "Wairarapa limestone." It is a coarse shelly rock, which appears to correspond to the Taueru limestone, and according to McKay's reports extends from Taueru in a south-south-west direction almost continuously to within two or three miles of the north-east shore of Palliser Bay. Thus it is found on the Maungaraki Range in Wairarapa South and Featherston counties, and presumably somewhat farther west also. It is seen in a gorge of the Hautotara River (presumably the Huangarua of present-day maps) east of Featherston, and is prominent on the hills to the south overlooking the Wairarapa Plain—for instance, east of Pirinoa—but, as already stated, disappears before reaching Palliser Bay.

In a recent article (Jour. Agri., vol. 11, No. 5, Nov., 1915, p. 410) B. C. Aston states that there are two suitable sites for quarries at Pirinoa, where the uppermost limestone strata are (moderately) soft, and contain about 80 per cent. of calcium carbonate. Very little crushing would suffice to reduce this material to a form suitable for application to the land, and experiments to ascertain its value as a soil-dressing ought to be made.

The following analyses probably all represent the Tertiary limestone of Featherston County :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Matter insoluble in acid, silica, &c.	3·20	1·69	..	0·50	3·79	65·72	35·00
Alumina and iron oxides ..	1·98	2·01	..	0·28	0·11	10·00	6·80
Calcium carbonate	91·35	93·37	60·82	98·27	94·81	18·56	53·90
Magnesium carbonate, &c. ..	3·16	2·69	..	..	1·29	..	..
Water, &c...	0·31	0·24	..	..	..	4·06	3·33
	100·00	100·00	..	99·05	100·00	98·34	99·03
Quicklime in calcined rock, per cent. (Aston)	87	90	..	96	90	..	..

	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Matter insoluble in acid, silica, &c.	6·64	9·96	1·84	29·40	15·40	12·60	15·40
Alumina and iron oxides ..	1·60	2·94	1·21	3·60	2·20	2·30	2·10
Calcium carbonate	89·60	85·89	95·89	60·70	79·20	82·90	79·00
Magnesium carbonate, &c. ..	..	..	..	6·30	3·20	2·20	3·50
Water, &c...	1·14	1·36	1·18	..	..	..	..
	98·98	100·15	100·12	100·00	100·00	100·00	100·00
Quicklime in calcined rock, per cent. (Aston and others) ..	84·4	79	94·8	46	68	73	68

References.—(1) Forwarded from Greytown by D. Henderson. Col. Mus. and Lab. 23rd Ann. Rep., 1889, p. 55. Lab. No. 4920. " A good stone for burning into lime."

(2) Reddish limestone, from Turanganui, Martinborough, forwarded by Iraia te Whaite. Col. Lab. 33rd Ann. Rep., 1900, p. 10. Lab. No. 8351. In this sample there was only a " trace " of alumina. The red colour was due to sesquioxide of iron. " A capital limestone, adapted for building purposes and also for burning into lime."

(3) From Homeburn, Martinborough, forwarded by W. Clark. Dom. Lab. 43rd Ann. Rep., 1910, p. 11. Lab. No. 2329.

(4) From " Featherston," forwarded by J. A. Toogood. Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 364.

(5) From " Featherston," forwarded by E. Aitchison. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 1087. " A first-class limestone."

(6) to (10) From Pirinoa, eighteen miles south of Martinborough. Dom. Lab. 43rd Ann. Rep., 1910, p. 52. Lab. Nos. L 57 to L 61. L 57 is a calcareous sandstone, and L 58 is a highly arenaceous limestone. The other three samples represent good limestones.

(11) to (14) From Pirinoa. B. C. Aston, in article already mentioned (1915), p. 410. Analyst's Nos. G 495, 496, 497, 498. No. 11 is soft limestone. No. 12 is medium stone from cliff above No. 11. No. 13 is similar stone from highest part of cliff. No. 14 is fairly hard stone.

In some of the beds below the limestone at White Rock Station and elsewhere calcareous concretions (septaria) are more or less abundant. Highly calcareous greensands, which may also contain appreciable amounts of potash and phosphate, outcrop on the north-east shore of Palliser Bay (McKay, 1879 report, p. 81).

J. C. Crawford and A. McKay mention that travertine occurs in considerable quantity at " Te-pura-pura," " Hautotara," and other points on the eastern side of the Wairarapa Valley (Crawford, 1861, 1870 ; and McKay, 1878 report, p. 16).

Summary of Limestone Resources and of Means of Transport.

Featherston County, like Wairarapa South, appears to contain sufficient limestone of good grade to supply all agricultural requirements. Systematic exploration and sampling are, however, necessary. The north-western part of the county is crossed by the Wellington–Wairarapa–Napier Railway, and can obtain supplies of lime from Mauriceville, which is only thirty-three miles from Featherston. A branch railway from Featherston to Martinborough is projected, and has in fact been constructed as far as Featherston Military Camp. This will bring the limestone east of Martinborough within reach of the railway system, and if the stone is in quantity and of the quality indicated by analyses Nos. 1, 2, 4, and 5 of the table above it will no doubt be profitably worked.

Literature.

Crawford, J. C.: Report in Council Papers of the Province of Wellington, 24th October, 1861. Not seen. Quoted by McKay in 1878 report, p. 16. See also Trans. N.Z. Inst., vol. 2, cited below.

Trans. N.Z. Inst., vol. 1, 2nd ed., 1875, pp. 309, 312, 313, 320, 321, 324, 325, &c. (Crawford); vol. 2, 1870, pp. 343 (travertine), 345, 348–51 (travertine), &c., (Crawford).

Rep. of Geol. Explor., No. 11, 1878, pp. 14–24; No. 12, 1879, pp. 75–86; No. 13, 1881, pp. 11–12; No. 19, 1888, pp. xxxiv, 1–6, 58–67.

Parl. Paper C.–9, 1899, pp. 36–43 (W. A. McKay); C.–10, 1901, pp. 28–32 (W. A. McKay). These papers are bound with the Mines Reports for their respective years.

Sollas, W. J., and McKay, Alex.: "Rocks of Cape Colville Peninsula," vol. 2, 1906, pp. 178–85 (description of rocks from east shore of Palliser Bay).

71 AND 72. HUTT AND MAKARA COUNTIES.

These two counties are composed almost entirely of old Mesozoic greywackes and argillites. In one horizon at least these rocks contain bands of diabasic tuff (more or less calcareous). A patch of Late Tertiary (or perhaps Pleistocene) rocks occurs in the Makara Valley, west of Wellington. In places, especially on the southern coast, raised beaches at various elevations can be traced. A prolongation of the Wanganui Plain reaches to Paraparaumu in Hutt County, where it is fringed on the ocean side by the usual sandhills. Sandhills are also seen on other parts of the coast wherever there is an inlet, bay, or flat land on which sand may accumulate. The Lower Hutt Valley contains fairly extensive areas of river-plain, built of gravels brought from the Tararua and Rimutaka mountains by the Hutt River and its tributaries. There are small flats bordering the shores of Porirua Harbour; and the valleys of the Orongorongo, Wainui-o-mata, and one or two other streams contain narrow river-flats covered by gravel and silt.

No limestone occurs in Hutt or Makara counties, but the Tertiary shelly rock of Makara Valley is highly calcareous. A little travertine probably occurs on or close to a raised beach on the south coast of Makara County, near to or west of Sinclair Head.

The occurrence of somewhat numerous flints and a few pebbles of a close-grained limestone on the low raised beach of Breaker Bay, near Seatoun, may be mentioned as a fact for which a sufficient explanation cannot easily be found.

The following analyses of calcareous rock, all from Makara County, may be quoted:—

	(1)	(2)
Matter insoluble in acid, silica, &c.	0·21	74·23
Alumina	0·30	..
Iron oxide	Traces	..
Calcium carbonate	96·85	24·46
Magnesium carbonate	2·64	1·11
Water	..	0·20
	100·00	100·00

References.—(1) Limestone boulder from gravel deposits, Tinakori Road, Wellington Pure-white in colour, fine-grained. Col. Mus. and Lab. 19th Ann. Rep., 1885, p. 26. Lab. No. 3684.

(2) Fossiliferous calcareous sandstone, South Makara, forwarded by T. H. Robinson. Col. Lab. 30th Ann. Rep., 1897, p. 11. Lab. No. 7233.

Analysis No. 3, below, perhaps represents a diabasic tuff :—

	(3)
Carbonate of lime	21·13
Carbonate of magnesia	0·89
Lime (as silicate taken up by acid)	3·40
Magnesia as silicate	4·63
Iron oxide and alumina	18·79
Siliceous matter (undecomposed)	50·01
Water	1·15
	100·00

Reference.—Calcareous serpentinous slaty rock with veins of hæmatite, from Makara, forwarded by Alex. McKay. Col. Mus. and Lab. 24th Ann. Rep., 1890, p. 26. Lab. No. 4964/A.

Means of Transport, &c.

Hutt and Makara counties do not possess any measureable limestone deposits, but are sufficiently fortunate in having the magnificent harbour of Port Nicholson, with the City of Wellington on its shores. The areas not occupied by towns and villages are largely pastoral, and therefore do not need lime to any great extent. This statement, of course, does not apply to the flat lands of the Hutt Valley, and to the hilly country occupied by dairy farms that supply milk to Wellington City and suburbs. Lime as needed may, however, either be imported by sea from Nelson to Wellington or by rail from Mauriceville, &c. The distance from Mauriceville to Wellington by rail is seventy-eight miles, and to Paraparaumu via Wellington 111 miles. From the limestone east of Martinborough the distances, when the branch railway-line to that town is made, will be considerably less. When the proposed Rimutaka deviation is constructed the length and difficulty of haulage will be reduced still more.

Literature, &c.

The chief references to the geology of Hutt and Makara counties in the literature consulted are—

Trans. N.Z. Inst., vol. 1, 2nd ed., 1875, pp. 307, 308, 309, 321, 324, 325 (Crawford); vol. 2, 1870, pp. 344–45, 347–48 (Crawford); vol. 21, 1889, pp. 486–87 (McKay); vol. 48, 1916, pp. 76–86 (F. K. Broadgate).

Rep. of Geol. Explor., No. 9, 1877, p. 54 (Tertiary rocks at Makara); No. 12, 1879, pp. 131–35; No. 15, 1883, pp. xxi, 85–88; No. 16, 1884, pp. 11–12; No. 19, 1888, pp. xl, 1–6, 67–71; No. 20, 1890, pp. 63–64; No. 21, 1892, pp. 35–38, 155; No. 22, 1894, pp. 91–92.

Parl. Paper C.–9, 1899 (bound with Mines Rep.), pp. 2–3.

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914, p. 147 (2nd ed., 1915). 9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, p. 83. 11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1917, p. 6.

In addition to the literature cited, J. C. Crawford and others have written a number of papers dealing with geological features near Wellington. Most of these will be found in the Trans. N.Z. Inst. See index to first forty volumes, under "Crawford," "Travers," "McLeod," &c. For sand-dune literature see Dr. L. Cockayne's reports (C.–13, 1909, and C.–13, 1911) cited under "Manawatu County." Dr. C. A. Cotton has written a paper entitled "Notes on Wellington Physiography," which appears in Trans. N.Z. Inst., vol. 44, 1912, pp. 245–65, and ought to have been cited above. See also an earlier paper by Dr. J. M. Bell in vol. 42 of the Transactions.

CHAPTER III.

LIMESTONE IN THE SOUTH ISLAND.

PAGE
1. Collingwood County 164
2. Takaka County 170
3. Waimea County 174
4. Sounds County 181
5 Marlborough County .. 181
6. Buller County 184
7. Murchison County 192
8. Amuri County 195
9. Awatere County 197
10. Kaikoura County 203
11. Cheviot County 206
12. Inangahua County.. 208
13. Grey County 211
14. Waipara County 217
15. Westland County 224
16. Tawera County 232
17. Oxford County 233
18. Ashley County 235
19. Kowai County 236
20. Rangiora County 237
21. Eyre County 237
22. Malvern County 237
23. Paparoa County 238
24. Waimairi County 238
25. Heathcote County.. 238
26. Halswell County 238
27. Springs County 238
PAGE
28. Mount Herbert County 238
29. Akaroa County 238
30. Wairewa County 238
31. Selwyn County 239
32. Ellesmere County 241
33. Ashburton County 241
34. Mackenzie County 245
35. Geraldine County 246
36. Levels County 248
37. Waimate County 249
38. Waitaki County 251
39. Lake County 258
40. Vincent County 264
41. Maniototo County.. 266
42. Waihemo County 268
43. Waikouaiti County 371
44. Taieri County 273
45. Peninsula County 276
46. Fiord County 277
47. Wallace County 279
48. Southland County.. 281
49. Tuapeka County 284
50. Bruce County 285
51. Clutha County 288
52. Stewart Island County 288
53. Chatham Islands County and Outlying Islands.. 289

1. Collingwood County.

The oldest rocks in Collingwood County are included in a great series of marbles, schists of various kinds, quartzites, argillites, and greywackes, known as the Aorere Series. The upper part of the Aorere Series is of Ordovician age, and the lower part is possibly of Cambrian age, but the whole will here be considered as Ordovician. Above the Aorere Series comes the Haupiri Series, of Palæozoic age, composed of argillites, breccias, and conglomerates. It does not appear to be of much importance. The Aorere rocks are well developed on both sides of the Aorere Valley, and extend over a large part of north-west Nelson. They are intruded by great masses of granite and other igneous rocks.

Much younger than all the rocks just mentioned are strata of Tertiary age, consisting of conglomerates, sandstones, shales, limestones, and calcareous claystones. Coal occurs in these beds at two horizons. The Tertiary rocks appear in the valley of the Aorere River from a few miles above Collingwood to the junction of Brown River with the Aorere. They also form a considerable part of the Cape Farewell Peninsula, and extend from its western side as a strip down the west coast to near Kahurangi Point. They are again seen at Heaphy River and Kohaihai Point. The youngest rocks of the Collingwood district are some patches of morainic gravels on the high country, the river-gravels of the Aorere Valley, &c., and the sand-dunes of Cape Farewell Spit.

As already indicated, the limestones of Collingwood County belong to two widely separated geological periods—one Early Palæozoic, the other Tertiary.

The limestone formed during the earlier period has been greatly altered by crustal movements and by solution and redeposition acting through long ages. In consequence it is now a marble in which little trace of its original structure can be detected. A small lens of this rock appears in the headwaters of Otere Stream, near the east boundary of Collingwood County. Of much greater importance is the marble or crystalline limestone that outcrops on the southern side of Parapara Inlet, and thence extends through the county in a general southerly direction for several miles, finally crossing the south-eastern boundary into Takaka County. The belt widens from a few hundred feet at Parapara Inlet to more than a mile on the county boundary. Belts of similar marble occur westward of this belt in the valleys of the Parapara and Slate rivers. A small lens crosses Wakefield Gully about three miles south-east of Bainham.

Still farther westward marble is said to occur in several of the streams draining into the Aorere River from the Wakamarama Range, and there are narrow lenses in both the headwater branches of the Paturau. Crystalline limestone forms a considerable part of Mount Burnett, and occurs at several other points north of Collingwood—for example, near the old graphite-mine at Pakawau.

The boundaries of the marble belts south of Parapara Inlet, and those in the valleys of the Upper Parapara, Slate, and Paturau rivers, were carefully mapped by the Geological Survey in the years 1906–7. The reader is therefore referred to the letterpress and maps of N.Z. Geol. Surv. Bull. No. 3 for fuller information concerning these belts than can be given here.

The quantity of limestone in the marble areas of Collingwood County is practically unlimited. Generally the carbonate-of-lime content is very high. In some places the marble is magnesian or dolomitic, and near the Parapara iron-ore deposit it may contain a good deal of carbonate of iron. There are also areas where the marble is siliceous.

The following analyses give a good idea of the varying composition of the Collingwood marbles and allied rocks, but the reader ought to remember that nearly pure or moderately siliceous calcium-carbonate rock predominates in most localities. Many of the samples were selected not as average samples, but to exemplify some special feature. Hence some of them, especially those high in silica, are not to be considered as representative of large bodies of stone.

	(1)	(2)	(3)	(4)	(5)
Carbonate of lime	48·61	90·12	88·96	86·71	99·1
Carbonate of magnesia ..	1·63	2·79	2·94	2·31	..
Alumina	1·92	4·58	2·21	0·89	0·4
Iron oxides				Trace	
Matter insoluble in acid ..	47·60	2·40	5·60	9·92	0·5
Water	0·24	0·11	0·29	0·17	..
	100·00	100·00	100·00	100·00	100·0

References.—(1) Calcareous sandstone from Ruataniwha, Collingwood, forwarded by Mr. J. R. Rees. Col. Mus. and Lab. 17th Ann. Rep., 1882, p. 29. Lab. No. 3075/1.

(2) (3) Marbles. Same locality, contributor, and reference as (1). Lab. Nos. 3075/2, 3 " The marbles are of excellent quality."

(4) Limestone, forwarded by Mr. W. R. Rees (perhaps J. R. Rees: see above) from Ferntown, near Collingwood. Col. Mus. and Lab. 18th Ann. Rep., 1883, p. 45. Lab. No. 3378/4 (probably).

(5) A very pure limestone from Pakawau, forwarded by Mr. E. G. Pilcher. Col. Lab. 40th Ann. Rep., 1907, p. 15.

Analyses Nos. 2 and 3 of the above table represent Ordovician marbles, and Nos. 1, 4, and 5 probably also represent rocks of the same age.

About 1890 Mr. C. Brown forwarded two samples of highly crystalline limestone or marble from Parapara to the Colonial Laboratory. These contained 96·71 and 96·82 per cent. of carbonate of lime. (Col. Mus. and Lab. 25th Ann. Rep., 1891, p. 57. Lab. Nos. 5374/1, 2.)

In 1907 Mr. J. W. Poynton, Public Trustee, forwarded two samples of almost pure calcite (calcium carbonate) to the Dominion Laboratory. They contained only traces of phosphoric acid. (Dom. Lab. 41st Ann. Rep., 1908, p. 18. Lab. Nos. 1085/1, 2.)

In 1916 Mr. J. Bassett forwarded a sample of grey marble from Turnbull's iron lease, Waitapu Survey District, which yielded on analysis 16·56 per cent. insoluble in acid, 78·75 per cent. calcium carbonate, and 2·58 per cent. magnesium carbonate. (Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. No. G 77.)

The following eight analyses represent limestones and marbles from the Parapara district :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Silica (SiO_2)	43·00	1·38	11·15	5·30	24·08	24·70	2·45	15·40
Alumina (Al_2O_3)	1·93	0·85	1·86	1·39	3·20	0·96		
Ferric oxide (Fe_2O_3)	1·12	0·40	2·24	1·44	2·27	0·32	0·65	5·91
Ferrous oxide (FeO)	..	0·22	..	0·29	0·26	6·55		
Manganous oxide (MnO)	1·02	0·32	..	0·70	0·25	0·28	..	..
Lime (CaO)	28·60	54·20	46·50	50·50	36·85	22·45	55·65	43·16
Magnesia (MgO)	..	0·10	0·15	0·10	1·85	12·48	0·25	0·41
Titanium oxide (TiO_2)	0·30	0·02	..	0·11	0·19	0·02	..	..
Carbon dioxide (CO_2)	22·32	42·30	36·10	40·17	30·10	32·20	40·62	31·16
Loss on ignition	1·71	0·35	..	0·25	0·40	0·15	..	..
Water and organic matter ..	..	..	0·99	..	..	..	0·30	3·31
Alkalies and undetermined ..	..	..	1·01	..	..	..	0·08	0·65
	100·00	100·14	100·00	100·25	99·45	100·11	100·00	100·00
Calcium carbonate (per cent.) ..	50·73	95·89	81·66	90·18	63·77	40·89	91·68	69·80
Magnesium carbonate (per cent.) ..	..	0·21	0·32	0·21	3·89	26·21	0·53	0·86
Quicklime in calcined stone (per cent.)	..	94·3	73·9	84·4	..	..	94·2	65·9

References.—(1) Arenaceous limestone from "Limestone Point," Parapara Inlet. N.Z. Geol. Surv. Bull. No. 3, 1907, p. 58. Lab. No. 905/32. This is a Tertiary limestone; Nos. 2 to 6 are of Palæozoic age.

(2) Crystalline limestone on road from Parapara Hall to Mr. J. Bassett's house. Lab. No. 905/54.

(3) Impure carbonate rock (siliceous marble) from extreme north of Washbourn Block, immediately south of Parapara Inlet. Lab. No. 1119/4.

(4) Weathered carbonate (marble) from Tukurua Stream. Lab. No. 905/47.

(5) Siliceous carbonate (siliceous marble) from Onakaka Stream. Lab. No. 905/3.

(6) Cherty rusty carbonate from contact with ultra-basic rocks, Parapara River gorge. Lab. No. 905/1.

The samples represented by the above analyses were collected in the years 1906–7 by the Geological Survey. Analyses Nos. 2 to 6 are published in N.Z. Geol. Surv. Bull. No. 3, 1907, p. 38 (not in same order as here).

(7) (8) From Parapara, forwarded by John Hayes. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. Nos. A 111/1, 2. Probably Palæozoic marbles.

An abundant and cheap supply of magnesian limestone or dolomite is of importance in connection with the manufacture of steel by the basic-hearth process. The following analyses are therefore of general interest :—

	(1)	(2)	(3)	(4)	(5)
Silica	1·03	0·57	8·83	3·22	1·50
Alumina	..	0·32	0·24	0·33	0·83
Ferric oxide	1·31		5·76	8·92	11·32
Lime	29·97	32·21	26·97	34·39	32·62
Magnesia	20·29	19·92	16·65	10·21	11·21
Carbonic anhydride ..	45·86	46·92	41·56	41·99	41·86
Phosphoric anhydride ..	..	..	0·06	..	..
Water and organic matter ..	0·51	..	0·08	0·79	0·18
Alkalies	..	0·06	..	..	..
Undetermined	1·03	..	..	0·15	0·48
	100·00	100·00	100·15	100·00	100·00
Carbonate of lime (per cent.)	53·50	56·84	48·16	61·41	58·25
Carbonate of magnesia (per cent.)	42·61	41·83	34·97	21·44	23·54

References.—(1) Dolomite from Collingwood Coal-mining Company's lease. Col. Mus. and Lab. 8th Ann. Rep., 1873, p. 16, and 9th Ann. Rep., 1874, pp. 15–16. Perhaps from dolomite bed in Tertiary coal-measures.

(2) Magnesian limestone from a locality north-west of Collingwood, forwarded in 1915 by Mr. John Hayes to the Geological Survey. Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. No. F 255.

(3) Magnesian limestone from Parapara, forwarded in 1913 by Inspecting Engineer, Mines Department (sample collected by Mr. F. G. Gibbs). Dom. Lab. 47th Ann. Rep., 1914, p. 23. Lab. No. D 990/1. Sulphur trioxide 0·10 per cent. Probably same locality as Nos. 4 and 5.

(4) (5) Magnesian limestones from near Richmond Flat, forwarded by Mr. J. Bassett. Same reference as No. 3. Lab. Nos. D 1243/4, 5.

Analyses of five other samples of magnesian limestone (all siliceous) from Parapara will be found on page 23 of the Dom. Lab. 47th Ann. Rep. These, so far as known, all came from the neighbourhood of Richmond Flat. Analysis D 990/2, given on the same page as the analyses just mentioned, represents a magnesite-serpentine rock, not a magnesian limestone or dolomite. Analysis D 1129/1, also on the same page, represents a highly siliceous rock.

The Tertiary limestone of the county has its principal exposure in the western portion of the district, where it forms an almost continuous strip extending from a point six miles south-west of Cape Farewell to the Big River. There is also a patch of apparently good limestone on the north side of the mouth of the Heaphy River. Here a large area of calcareous beds is exposed, extending for two miles and a half up the valley of the Heaphy and over a part of the basin of the Gunner River. Small patches of limestone, which seem to be of good quality and rest almost directly on the basal rocks, are to be found at several points on the Gouland Downs. In the valley of the Aorere River patches of limestone occur at several places near Bainham, at Fifteen-mile Creek, and at " The Castles " on the Quartz Ranges. There is also a small area of Tertiary limestone on the west side of Parapara Inlet. This extends south-west up the valley of the Parapara River to a point west of trig. station DW. An analysis of material from Limestone Point has already been quoted.

The limestone of the belt near the western coast varies in quality, and in many places passes into a calcareous sandstone.

The following six analyses represent samples of flaggy arenaceous limestone collected in 1907 by the late Mr. E. J. H. Webb, then a member of the Geological Survey staff, from Sandhill Creek and the coast-line north of Sandhill Creek towards the Paturau River. The limestone dips gently to the north-north-west, and is overlain by soft calcareous sandstone (" papa ").

	(1)	(2)	(3)	(4)	(5)	(6)
Silica	12·45	10·12	9·42	11·10	14·72	19·38
Alumina	1·22	1·24	1·21	1·32	1·45	2·55
Iron oxides	1·30	1·06	1·04	1·00	0·92	1·02
Lime	46·96	47·74	48·30	47·78	46·13	42·90
Magnesia	1·12	1·83	1·25	0·75	0·42	0·42
Carbonic anhydride ..	36·90	37·52	37·95	37·54	36·25	33·70
Moisture and organic matter	0·05	0·49	0·83	0·51	0·11	0·03
	100·00	100·00	100·00	100·00	100·00	100·00
Calcium carbonate (per cent.)	81·07	80·70	83·11	83·43	81·34	75·55
Magnesium carbonate (per cent.)	2·35	3·84	2·63	1·58	0·88	0·88
Quicklime in calcined stone (per cent.)	74·5	77·0	78·9	77·1	72·5	64·7

References.—(1) From a point 50 ft. below top of limestone cliff, south-west side of Sandhill Creek (some distance from the mouth).

(2) From same cliff as No. 1.

(3) From coast-line north of Sandhill Creek, between stations 3 and 4 (over one mile and three-quarters north of mouth of Sandhill Creek).

(4) From station 3, one mile and three-quarters north of mouth of Sandhill Creek.

(5) From between stations 4 and 5, on beach about two miles north of Sandhill Creek.

(6) From last outcrop on beach north of Sandhill Creek (near Paturau River, and two miles and a half or more north of Sandhill Creek).

The above analyses are to be found in Dom. Lab. 41st Ann. Rep., 1908, p. 22. Lab. Nos. 1517/1–6.

Mr. Webb also collected two samples of the soft calcareous sandstone or "papa" overlying the limestone from points on the coast south and north of Sandhill Creek. These had the following composition:—

	(1)	(2)
Silica	37·62	46·97
Alumina	5·65	7·30
Ferric oxide	3·61	4·24
Lime	25·20	18·72
Magnesia	2·18	2·28
Potash	1·34	1·71
Soda	1·57	1·86
Carbonic anhydride	18·60	13·60
Water and organic matter	3·57	3·12
	99·34	99·80

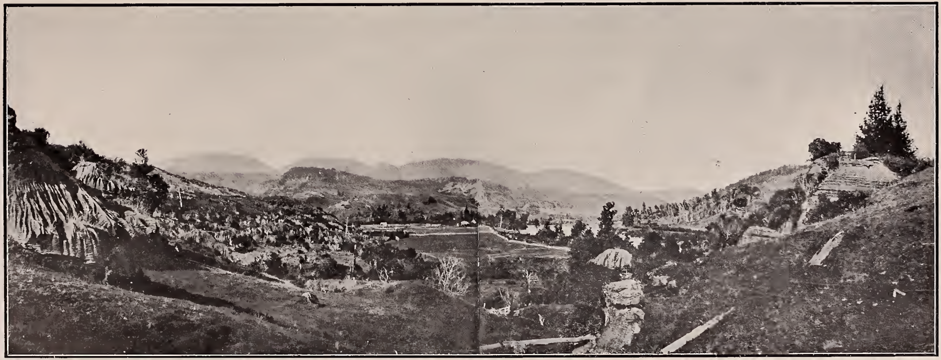
References.—(1) From coast-line south of Sandhill Creek. Lab. No. 1518/1.

(2) From beach between mouth of Sandhill Creek and "The Blowhole." Lab. No. 1518/2. "The Blowhole" is about a mile north of Sandhill Creek.

The principal area of agricultural land in Collingwood County is in the neighbourhood of Bainham, a settlement on the west bank of the Aorere River, ten miles from Collingwood. Numerous isolated fragments of Tertiary limestone occur in the vicinity, but most of these are on the high terrace slopes on the eastern side of the river. More advantageously placed is a small area of flat-lying limestone 10 chains, more or less, below the road-crossing of the Silverstream, a brook flowing into the Aorere about two miles and a half south of the post-office and cheese-factory. This deposit rests directly upon, and contains occasional rounded pebbles of, the basal schist. The rock when the locality was visited was covered with fern and scrub, and it was impossible to ascertain the thickness of the various layers. Caves occur, and samples were taken from their neighbourhood. No. 2 in the table of analyses following the next paragraph shows the composition of a sample from the lowest 12 ft. of rock exposed at the caves. The sample represented by No. 3 was taken from an overlying 10 ft. layer, in which the rock was more arenaceous and decidedly softer. The deposit is not well situated for cheap working, its base being at stream-level and below the general surface of the flat. Residents, however, consider it the most accessible limestone in the district, and agree that any lime-treatment plant ought to be placed here. (Departmental report by Dr. J. Henderson.)

The limestone at "The Castles," five miles south of Bainham, appears to be in part of good quality, as is shown by analysis No. 4 of the table below. There is probably good limestone at Bungapore, two miles east of Bainham, and at the caves less than a mile to the north-east of the Bungapore limestone. The position of the numerous other patches of Tertiary limestone in the Aorere Valley will best be ascertained by consulting the geological map of Aorere Survey District in N.Z. Geol. Surv. Bull. No. 3. According to that bulletin the limestone of the Aorere Valley is in general exceedingly argillaceous, and in the lower layers it is frequently arenaceous. The thickness does not exceed 50 ft.

PLATE VIII.



Limestone Buttes (Hills) in Valley of Aorere River above Rockville.

Geol. Bull. 22] [*To face p. 168.*

The following analyses represent the Tertiary limestones of the Aorere Valley :—

	(1)	(2)	(3)	(4)	(5)	(6)
Silica (SiO_2)	20·10	8·81	22·68	6·40	18·30	31·10
Alumina (Al_2O_3)	1·10	..	..	1·82	5·93	11·44
Iron oxides (FeO and Fe_2O_3)	..	..	..	1·18	1·92	3·36
Lime (CaO)	43·78	47·90	40·60	49·10	39·75	28·20
Magnesia (MgO)	..	..	..	0·12	0·15	0·10
Carbon dioxide (CO_2)	34·40	..	..	38·10	30·80	21·40
Water and organic matter	..	0·48	0·59	1·40	1·60	3·26
	99·38	..	..	98·12	98·45	98·86
Calcium carbonate equivalent to lime present (per cent.)	78·18	85·54	72·50	87·68	70·98	50·36
Quicklime in calcined stone (per cent.)	66·7	76·8	59·6	81·2	58·8	38·8

The figures in the lowest two lines of the table above are approximate, and those for calcium carbonate in all or most cases too high. As explained in Chapter I, there are different ways of calculating the percentages of calcium carbonate, &c., from an analysis, and these lead to slightly different results. If the analysis is incomplete the best method cannot always be chosen.

References.—(1) From Bainham, forwarded by E. B. Langford. Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 971.

(2) Lower 12 ft. of limestone, 10 chains south of Silverstream, three miles south-west of Bainham. Lab. No. G 1579 as originally recorded, but in Dom. Lab. 50th Ann. Rep., 1917, p. 21, the number is given as G 1578/2.

(3) Upper 10 ft. of limestone, 10 chains south of Silverstream, three miles south-west of Bainham. Lab. No. G 1578 as originally recorded, but G 1578/1 in Dom. Lab. 50th Ann. Rep., 1917, p. 21.

(4) Lower part of outcrop at "The Castles," five miles south of Bainham. N.Z. Geol. Surv Bull. No. 3, pp. 57–58; and Dom. Lab. 41st Ann. Rep., 1908, p. 19. Lab. No. 1216.

(5) Lower part of outcrop at "The Castles." Same references as No. 3. Lab. No. 1220.

(6) Fifteen-mile Creek, Aorere River. Same references as No. 3. Lab. No. 1221.

Summary of Limestone Resources and of Means of Transport.

Although the Ordovician marbles of Collingwood County are in places more or less siliceous, and occasionally magnesian as well, yet there are enormous quantities of high-grade stone, suitable for agricultural purposes, for building, and for use as a flux for the iron-ore south of Parapara Inlet, which happens to be associated with the largest marble belt in the county. Much of the magnesian limestone near Richmond Flat, unfortunately, is siliceous, but the purer portion, if found in quantity, will be of great value (after calcination) for basic linings to steel-furnaces. Pure magnesian limestone and dolomite occur in unknown amount north-west of Collingwood (near Mount Burnett).

Tertiary limestone occurs in many localities, and in the aggregate may be regarded as unlimited in quantity. As a rule, however, it is not high grade, and is therefore better adapted for pulverization than calcination.

The mountainous nature of Collingwood County causes many of the limestone deposits to be difficult of access. Some of those in the Aorere Valley are fairly accessible, but are situated in so low a position as not to be easily mined.

The county has no railway, most of the roads are poor, and internal communications are therefore inconvenient. Golden Bay, on the north coast, may be regarded as potentially a good port, but near the shore is very shallow. There are wharves for small vessels at Tukurua Point, Collingwood, Seaford, and Puponga. West Wanganui Inlet, or Westhaven, is a harbour for vessels of medium size, whilst the Paturau and some of the other streams to the south can be entered by small steamers. The sea communications of Collingwood County are therefore fairly good.

Literature.

A part of Collingwood County has been geologically surveyed in detail, and the results will be found in N.Z. Geol. Surv. Bull. No. 3, 1907, "The Geology of the Parapara Subdivision, Karamea, Nelson," by J. M. Bell, E. J. H. Webb, and E. de C. Clarke. This publication describes the geology of Aorere and Waitapu survey districts. The latter district is only partly in Collingwood County. A considerable area west and south of the Parapara Subdivision has been in part geologically and topographically surveyed by E. J. H. Webb, H. Richardson, H. S. Whitehorn, and others, but the surveys remain unfinished and the results unpublished.

No part of New Zealand has been more frequently visited by geologists than Collingwood County, and twenty-five or more official reports of various kinds have been made. Had the energy employed in making the numerous examinations reported in the geological literature been systematically controlled, a detailed geological survey of the whole county would have been completed long ago. Bulletin No. 3, mentioned above, contains a list of sixty publications dealing with the geology and mineral resources of the Collingwood–Parapara district. To these may be added the following:—

Rep. of Geol. Explor., No. 4, 1868, pp. 18–22; No. 6, 1871, pp. 157–58; No. 7, 1872, pp. 158–65.

Parl. Paper C.–6, 1900 (bound in Mines Rep.), pp. 1–5.

Trans. N.Z. Inst., vol. 41, 1909, pp. 101–2; vol. 43, 1911, part of pp. 297–315; vol. 48, 1916, pp. 59–75.

The most exhaustive report on the county as a whole is that of Park in Rep. Geol. Explor., No. 20, 1890, pp. 186–243.

2. TAKAKA COUNTY.

The geology of Takaka County is similar to that of Collingwood County. On either side of the Takaka Valley are mountain-ranges composed of Palæozoic sedimentary and igneous rocks of much the same types and ages as those of Collingwood County. The wide lower Takaka Valley is covered by a veneer of river-gravels, under which lie Tertiary conglomerate, sandstone, limestone, and claystone. Limestone-capped patches of these rise above the general level of the valley-floor, and appear also on the mountains in the southern part of the county near Gordon's Pyramid, Mount Peel, &c.

The Ordovician marble belt in the east part of Collingwood County extends southward through the western part of Takaka County. Where crossed by the Waikoromumu Stream it is a mile and a half wide. South of the Anatoki River it has not been mapped, but appears to continue due south for many miles. There is also a small lens of marble east of the belt described above in Copperstain Creek, a tributary of Pariwhakaoho Stream. Great quantities of excellent marble occur east of the Takaka Valley in the Pikikiruna Range. A belt begins on the western side of the range south of Pohara, and on the southern border of Waitapu Survey District is over two miles and a half wide. It continues without interruption southward to the Mount Arthur district, where it passes out of the county. On the crest of the Pikikiruna Range Ordovician marble is further exposed, but is for the most part in Waimea County.

The Ordovician marble of Takaka County is generally of great purity. The available analyses are only two in number; and one of these, the first quoted below, is that of a sample selected for a special purpose, and not as representative of a large body of stone.

	(1)	(2)
Silica, or matter insoluble in acid	23·50	2·00
Alumina	2·81	..
Ferric oxide	3·84	..
Lime	42·30	52·00
Magnesia	0·15	..
Carbon dioxide	23·20	..
Loss on ignition	0·92	..
Alkalies and undetermined	3·28	..
	100·00	..
Calcium carbonate (per cent.)	52·34	92·86
Quicklime in calcined stone (per cent.)	55·7	86·7

References.—(1) Siliceous carbonate (marble) from contact with gneissoid granite at the base of the Pikikiruna Range. Geol. Surv. No. 276. N.Z. Geol. Surv. Bull. No. 3, 1907, p. 38; and Dom. Lab. 41st Ann. Rep., 1908, pp. 18–19. Lab. No. 1102/4. About 13 per cent. of lime appears to be in the form of silicate.

(2) Dark marble, Rameka Creek, Waitapu Survey District, collected by J. Henderson in 1916. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 1578/3.

Tertiary limestone is well seen on the coast at and south of Rangihaieta Head, east of Motupipi River near its mouth, on the coast from Pohara to Ligar Bay, on the north-east headland of Ligar Bay, and at Tata Islands. It forms a butte of several hundred acres north of Takaka, and two small flat-topped hills to the south. From Ligar Bay a belt of limestone extends on the east side of the Takaka Valley south-west along the base of the Pikikiruna Range. It is seen in Ellis Creek, Gibson Creek, Kitty Creek, Dry Creek, Rameka Creek, &c. There is a considerable patch east of the junction of the Waingaro and Takaka rivers. Tertiary limestone of fair grade appears on the slopes of Gordon's Pyramid (near Mount Arthur) at a height of 4,000 ft. or more, and farther to the west at the source of the Cobb River, whence it extends into the Leslie Valley (Buller County). Bell, Webb, and Clarke report that the limestone in the Takaka Valley reaches, but seldom exceeds, 100 ft. in thickness. The limestone on the high country near Gordon's Pyramid is perhaps not thicker. On the whole the Takaka Tertiary limestone is of better quality than that in Collingwood County. This is shown by the analyses quoted on the following pages.

At Rangihaieta Head the limestone does not exceed 50 ft. in thickness, and dips somewhat steeply at an angle of 35° to the north. It overlies quartz-grits, and, like the limestone seen elsewhere along the coast-line, is banded or flaggy, the bands averaging from 4 in. to 6 in. in width, and varying somewhat in the amount of sand they contain. The lower part is exceedingly arenaceous (sandy). The following analysis is stated to represent an average sample :—

Silica	11·00
Alumina	0·27
Ferric oxide	1·03
Lime	46·65
Magnesia	1·61
Carbonic anhydride	37·05
Water and organic matter	2·14
Alkalies and loss	0·25
	100·00
Calcium carbonate (per cent.)	80·18
Magnesium carbonate (per cent.)	3·38
Quicklime in calcined stone (per cent.)	76·7

Reference.—N.Z. Geol. Surv. Bull. No. 3, 1907, p. 58. Lab. No. 1119/9.

The limestone on the eastern bank of the Motupipi River extends from the river-mouth to near the bridge on the Takaka–Clifton Road. It apparently has a steep dip to the west, but the authors of Bulletin No. 3 state that this is due to the undermining action of the river, for the underlying strata are nearly horizontal. The limestone has been worked on a small scale for the manufacture of lime and cement. The following analyses indicate that it is of medium to good quality:—

I. Analyses of Motupipi Limestone prior to 1894.

	(1)	(2)	(3)	(4)
Carbonate of lime	74·93	67·88	68·01	89·44
Carbonate of magnesia	7·92	2·96	3·20	1·99
Alumina	0·74	0·81	0·72	0·93
Iron oxides	Traces			
Silica, or matter insoluble in acid	1·89	28·23	27·86	7·43
Bituminous matter	13·77	..	..	..
Water	0·75	0·12	0·21	0·21
	100·00	100·00	100·00	100·00

II. Analyses of Motupipi Limestone made since 1894.

	(5)	(6)	(7)	(8)	(9)	(10)
Silica	9·80	5·9	11·6	10·1	19·4	6·0
Alumina	2·09	2·2	4·4	3·1	2·2	2·8
Ferric oxide	1·76	1·0	1·1	0·8	0·8	0·3
Lime	46·60	50·5	45·8	47·7	43·0	50·6
Magnesia	0·20	0·6	0·8	0·6	0·5	0·4
Carbonic anhydride ..	35·80	39·7	36·0	37·5	33·9	39·8
Loss on ignition	1·45	..	..	..	..	..
Alkalies, &c.	2·30	..	..	..	..	..
Organic matter, &c. ..	..	0·1	0·3	0·2	0·2	0·1
	100·00	100·0	100·0	100·0	100·0	100·0
Carbonate of lime (per cent.)	80·86	88·7	79·8	83·7	75·8	89·5
Carbonate of magnesia (per cent.)	0·42	1·3	1·7	1·3	1·1	0·8
Quicklime in calcined stone (per cent.)	74·3	83·9	71·9	76·6	65·3	84·2

References.—(1) Highly carbonaceous limestone from Motupipi Coal-mine, forwarded by Mr. D. H. T. Ranson. Col. Mus. and Lab. 15th Ann. Rep., 1880, p. 36. Lab. No. 2664.

(2) (3) Fairly hard limestones from Motupipi, forwarded by Mr. James McDonald. Col. Lab. 28th Ann. Rep., 1894, p. 11. Lab. Nos. 6222/7, 8.

(4) Hard coherent shelly limestone. Same locality, contributor, and reference as Nos. 2 and 3. Page 12 of report. Lab. No. 6260/1.

(5) From French's Quarry, Motupipi River. N.Z. Geol. Surv. Bull. No. 3, 1907, p. 59; and Dom. Lab. 41st Ann. Rep., 1908, pp. 18–19. Lab. No. 1102/2. This is an average sample from French's Quarry (not River, as recorded in the Laboratory report).

(6) to (10) From Motupipi, forwarded by Mr H. H. Seabrook, Grafton Road, Auckland. Dom. Lab. 41st Ann. Rep., 1908, p. 20. Lab. Nos. 1239/1–5. Composition of burnt stone also given.

Between Pohara and Ligar Bay limestone forms cliffs along the coast. In this locality it attains a thickness of 200 ft. On the Tata Islands the limestone is well bedded, and in places shows thick beds of fossil oysters. It is being worked here and at Tarakohe on a small scale for the manufacture of cement by the Golden Bay Cement-works (Limited). This company can supply finely ground limestone for agricultural purposes from its works at Tarakohe, but the high first cost of the ground rock and the cost of transport prevent trade from developing to any great extent. The quarry-face at Tarakohe is from 60 ft. to 80 ft. high.

Analyses of limestone from Tarakohe (the site of the cement-works) and Tata Islands are—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Silica	6·5	5·14	4·57	5·35	8·53	5·40	7·72
Alumina	1·0	0·65	1·32	1·54	1·76	1·28	1·97
Ferric oxide	0·8	1·60	1·09	0·64	1·04	0·80	0·88
Lime	48·9	51·15	51·42	50·86	48·44	50·26	49·42
Magnesia	0·9	0·10	0·40	0·50	0·38	0·54	0·63
Carbonic anhydride	38·4	39·80	40·40	39·96	38·05	39·48	38·84
Water and organic matter ..	2·0	0·72	0·80	1·15	1·80	2·24	0·54
Alkalies and undetermined ..	1·5	0·84	..	..	..	..	..
	100·0	100·00	100·00	100·00	100·00	100·00	100·00
Calcium carbonate by addition of lime and carbonic anhydride (per cent.)	87·3	90·95	91·82	90·82	86·49	89·74	88·26
Quicklime in burnt stone (per cent.)	82·0	85·9	87·4	86·4	80·5	86·2	81·5

References.—(1) From Terakohe (Tarakohe), forwarded by the Secretary, Golden Bay Cement Company. Dom. Lab. 41st Ann. Rep., 1908, p. 21. Lab. No. 1414. The composition of the burnt stone is given.

(2) Average sample from Tata Island. N.Z. Geol. Surv. Bull. No. 3, 1907, p. 59. Lab. No. 1174/2. Date, 1907.

(3) to (7) From Tata Island, forwarded by the Under-Secretary for Mines, per Mr. Alex. McKay, Government Geologist. Dom. Lab. 42nd Ann. Rep., 1909, p. 20. Lab. Nos. 1645/1–5.

Two analyses, the sources of which have not been noted, ascribe 92 per cent. of calcium carbonate to a sample of limestone from the Takaka coast, and 85 per cent. to a sample from Tarakohe.

At the point where Rameka Creek breaks from the hills Tertiary limestone of good quality forms a low terrace near a road which leads to Clifton, and also connects with the road to the township of Takaka. Hills of dark fine-grained Ordovician marble rise a few chains to the eastward. This is perhaps the most central site for a limestone crushing or calcining plant in the lower Takaka Valley. At one time the Tertiary limestone near the junction of the Takaka and Waingaro rivers was calcined in a kiln for agricultural purposes, &c., but no lime has been produced for many years.

The following analyses represent Tertiary limestones from Pohara, Dry River, and Rameka Creek :—

	(1)	(2)	(3)	(4)
Silica	2·50	8·40	..	..
Matter insoluble in acid ..	..	..	11·90	3·10
Alumina	0·42	0·13	..	..
Ferric oxide	1·68	1·12	..	..
Lime	49·70	48·55	47·84	53·00
Magnesia	0·85	0·52	..	..
Carbonic anhydride	40·10	36·00	..	..
Loss on ignition	1·45	2·72	..	..
Water and organic matter ..	..	..	0·10	0·16
Alkalies and undetermined ..	3·30	2·56	..	..
	100·00	100·00	..	..
Calcium carbonate, equivalent to lime (per cent.)	88·75	86·70	85·43	94·64
Quicklime in calcined stone (per cent.)	85·0	79·2	82·5	91·1

Note.—The percentage of quicklime as calculated is too high for No. 3, and probably also for No. 4.

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* Various analyses of Tarakohe limestone are given by F. Reed in a description of the Golden Bay Portland Cement Company's works contained in Mines Statement, Parl. Paper C.–2, 1918, pp. 24–27. Analyst: Sydney F. Strudwicke.

References.—(1) (2) From coast between Pohara and Ligar Bay. N.Z. Geol. Surv. Bull. No. 3, 1907, p. 59; and Dom. Lab. 41st Ann. Rep., 1908, pp. 18–19. Lab. Nos. 1102/3, 9.

(3) From Dry River, collected by Dr. J. Henderson. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. 1578/5. Original Lab. No. 1582.

(4) From Rameka Creek. Same collector and reference as (3). Lab. No. 1578/4; original Lab. No. 1581.

Summary of Limestone Resources and of Means of Transport.

Takaka County has almost limitless supplies of high-grade crystalline limestone or marble of Ordovician age. There is also abundance of good Tertiary limestone in or near the chief agricultural district, the lower Takaka Valley. Most of the Tertiary limestones and some of the Palæozoic marbles are readily accessible, and therefore Takaka County has no reason to complain that nature was niggardly to that part of New Zealand when limestone was being formed. All that remains is for man to do his part in erecting lime-works and providing means of transport. As already stated, the best site for a central plant to produce either pulverized limestone or agricultural lime is at Rameka Creek, three or four miles south-east by road from the township of Takaka. The sheltered waters of Golden Bay give the county good sea communications There are small ports at Waitapu, Motupipi, and Tarakohe, and several bays farther east on both sides of Separation Point, but these run into the high land of the Pikikiruna Range and are of little use as harbours. In the thickly populated lower Takaka Valley the roads are good, and there is also a good road over the Pikikiruna Range to Motueka and thence to Nelson. A somewhat indifferent road leads to Collingwood. The inland mountainous part of the county has no means of communication other than a few bridle and foot tracks.

Literature.

That part of Takaka County which is in Waitapu Survey District has been geologically surveyed in detail, and the results are embodied in N.Z. Geol. Surv. Bull. No. 3, 1907. Many of the more general reports cited in the list of literature in that bulletin (pp. 8–11) have more or less reference to Takaka County. The following references may be given here :—

Rep. of Geol. Explor., No. 12, 1879, part of pp. 121–31 ; No. 13, 1881, parts of pp. x, 1–9 (see map opposite p. 2) ; No. 14, 1882, part of pp. 42–56 ; No. 20, 1890, parts of pp. lvii–lviii, and 186–243 (Park) ; No. 21, 1892, p. 21, part of pp. 38–43, 151 (Collingwood County).

Trans. N.Z. Inst., vol. 43, 1911, part of pp. 297–313.

Henderson, J. : "Marble in Riwaka-Takaka District." N.Z. Jour. Sci. and Tech., vol. 1, No. 3, May, 1918, pp. 175–77.

3. WAIMEA COUNTY.

Waimea is a large county with varied topography and geology. In the west, schists, marbles, argillites, and greywackes of Ordovician age (Aorere Series) occur. In the east are conglomerates, greywackes, and argillites of uncertain Palæozoic age (? Devonian), overlain by Permo-Carboniferous argillite, greywacke, and limestone, intruded by various igneous rocks. These are succeeded by Triassic conglomerate, greywacke, &c. Middle or Early Tertiary conglomerates, sandstones, shales, limestones, and claystones, with a certain amount of coal in the lower horizons, occur in strips and patches in various parts of the county, but are nowhere prominent. Late Tertiary gravels have a considerable development in the Moutere Hills and elsewhere. The youngest rocks of the district are the gravels and other alluvial deposits that form the surface of the Motueka and Waimea plains, and of the river-flats throughout the interior.

As mentioned under Takaka County, marble of Ordovician age occurs on the top of the Pikikiruna Range west of Riwaka, and extends as a wide belt for many miles to the southward. A narrower belt begins in the valley of Holyoake Creek, near Sandy Bay, and stretches southward for many miles. In the Riwaka Valley it is between 30 and 40 chains wide. This belt reaches Mount Arthur, and it or the belt a little to the west continues as far as Mount Owen, in Inangahua County, where marble is exposed over a wide area.

The marble of the Pikikiruna and Mount Arthur ranges is generally somewhat coarsely crystalline (hence the name " crystalline limestone ") and of light colour—white and various shades of grey. In places, however, other colours appear, and very handsome slabs have been obtained from quarries in the Riwaka and Sandy Bay districts. Very dark fine-grained marble occurs in several localities. The marble is generally of great purity, but portions are siliceous, and in places the stone contains pyrite (iron-pyrites), an objectionable constituent in building or ornamental stone. The western part of Waimea County contains practically inexhaustible supplies of high-grade marble, much of which is suitable for building purposes, and all is suitable for calcination or pulverization.

The marble in the lower part of Holyoake Creek strikes north-west and has an average dip of about 80° to the south-west. Owing to granitic intrusions the thickness varies, and has not been estimated, but probably reaches 1,000 ft. The following analyses show its composition :—

	(1)	(2)	(3)	(4)	(5)	(6)
Silica, or matter insoluble in acid	3·11	2·66	0·86	0·14	0·17	0·82
Alumina and iron oxides	0·20	0·51	0·25	0·21	0·20	0·11
Lime	53·10	52·64	54·30	55·87	55·60	55·16
Magnesia	0·64	0·65	0·30	0·10	0·10	0·47
Phosphoric anhydride	..	..	..	..	..	0·04
Carbonic anhydride	42·50	41·36	42·50	42·76	43·26	43·34
Iron-pyrites	0·06	..	0·04	0·01	0·05	..
Water and organic matter	..	0·80	0·47	0·30	0·30	0·08
Free carbon	..	0·06	..	..	0·05	..
Alkalies and undetermined	0·39	1·32	1·28	0·61	0·27	..
	100·00	100·00	100·00	100·00	100·00	100·02
Calcium carbonate (per cent.)	94·82	92·38	95·84	96·93	98·07	97·32
Magnesium carbonate (per cent.)	1·34	1·37	0·63	0·21	0·21	0·99
Quicklime (CaO) in calcined stone (per cent.)	92·4	91·1	95·2	98·1	98·6	97·5
Specific gravity	..	2·705	2·68	2·715	2·715	..

References.—(1) Marble from quarry in Marble Creek, Holyoake Valley, collected by Dr. J. A. Thomson in May, 1913. 7th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1913, p. 132 ; and Dom. Lab. 47th Ann. Rep., 1914, p. 20. Lab. No. D 485.

(2) Dark fine-grained marble from same quarry as No. 1, collected by P. G. Morgan in December, 1914. 9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, pp. 84–86 ; and Dom. Lab. 48th Ann. Rep., 1915, p. 18. Lab. No. E 1568.

(3) White coarse-grained marble, Messrs. Hugonin and Henderson's land, Upper Holyoake Creek (new quarry-site). Same references as No. 2. Lab. No. E 1569.

(4) White marble from quarry on Mr. Hobson's land, near road over Pikikiruna Range. Same references as No. 2. Lab. No. E 1570.

(5) Grey marble from same quarry as No. 4. Same references as No. 2. Lab. No. E 1571.

(6) General sample from stone being used for Parliamentary Buildings, Wellington. Sample collected by P. G. Morgan in May, 1917. Lab. No. H 901. This sample contained no organic matter and no soda or potash.

The New Zealand Marble and Cement Company some years ago opened several quarries in the lower part of Holyoake Creek valley (at Marble Creek, &c.), but these are now practically abandoned. During 1915–16 new quarries were opened at a height of about 1,200 ft. above sea-level in the upper part of the valley, on Messrs. Hugonin and Henderson's land, and a tram-line several miles in length constructed to the lower Otuwhero Valley, and thence to the old tram-line leading from Marble Creek to Sandy Bay. At the end of the tram-line is a wharf, whence the marble is shipped to Wellington in scows.

The Nelson Marble Company has opened a quarry on the top of the Pikikiruna Range, west of the Kairuru quarry in upper Holyoake Creek, where stone for the new Parliamentary Buildings is now being obtained. The locality is known as Ngarua. It is reached by a road half a mile in length, which has been constructed to the northward from a point on the road over the Pikikiruna Range eight miles from the Riwaka Bridge. The marble in the Ngarua quarry is of medium to coarse grain, and exhibits a pleasing contrast of colour, varying from white to dark-grey. Many large blocks occur on the surface, and the stone in the solid beneath is expected to be massive, with widely spaced joints. The strike of the rock is a few degrees east of north, and the dip to south of east at an angle of about 70°. A great quantity of fine building-stone is in sight.

In the lower Riwaka Valley the marble belt is nearly 40 chains wide, and this implies that the marble stratum is of great thickness (2,000 ft. or more), for the dip is steep, but the structure has not been worked out. On the south side of the Riwaka River, a few chains from the stream and about a mile west of the bridge on the main Motueka–Takaka Road, the Nelson Marble Company during 1916 stripped the face of a hill with a view to opening a quarry. The stone here is of medium grain. Not far away, on the north side of the Riwaka, a kiln for producing lime was in operation a few years ago.

The headwaters of the Riwaka River drain part of the broad belt of marble mentioned previously as occurring on the crest of the Pikikiruna Range. A road, which ends as a horse-track, leads up the Riwaka River to the junction of Flat Creek, a point about 560 ft. above sea-level. Half a mile up Flat Creek marble appears, and continues to the crest of the Pikikiruna Range. The upper part of Flat Creek flows in a wide, mature, basin-like valley, some miles south of the main road over the Pikikiruna Range. Almost the whole of the valley is floored by marble of varying grain and colour. At a cleft near the head where a small branch stream disappears the marble is light grey to dark grey, and even almost black in colour. It is well bedded, and free from pronounced joints. The strike is a little south of west, and the dip is southerly at an angle of about 25°. The locality is about 2,500 ft. above sea-level, and near the main divide of the Pikikiruna Range. In the gorge of Flat Creek, below the basin mentioned above, the marble is light-coloured, massive, and of medium to coarse grain.

The following analyses show the composition of the marble in the lower Riwaka Valley and in various districts farther south:—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Silica, or matter insoluble in acid	..	3·34	..	1·2	..	2·33	2·92
Alumina	..	..	..	0·3	..	..	2·27
Iron oxides	..	1·59	..	0·4	..	..	
Calcium carbonate	96·40	94·12	95·13	98·1	54·0	94·25	62·31
Magnesium carbonate	..	..	..	..	..	..	32·18
Moisture and organic matter	..	..	..	..	..	0·04	..
Graphite	..	..	..	..	..	..	0·32
	..	99·05	..	100·0	..	96·62	100·00
Quicklime (CaO) in calcined stone (per cent.)	93·7	90·0	91·6	96·7	..	90·2	..

References.—(1) From Riwaka, probably forwarded by Mr. T. B. Jacobson. Col. Mus. and Lab. 23rd Ann. Rep., 1889, pp. 54, 79. Lab. No. 4784 (probably).

(2) From Riwaka, forwarded by Director of Orchards, Agricultural Department. Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 316. "This stone would yield an excellent quicklime."

(3) From Motueka, forwarded by Hon. Minister of Mines. Dom. Lab. 43rd Ann. Rep., 1910, p. 11. Lab. No. 2282.

(4) (5) From Baton River, forwarded by Mr. James Ness. Col. Lab. 40th Ann. Rep., 1907, p. 15. Lab. Nos. 853/1, 2. Sample 853/2 may not have been from the marble belt.

(6) From Drummond's Run, Wangapeka Valley, collected by J. Henderson (Geological Survey) in 1916. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 1583 (or, as published, 1578/6).

(7) Graphitic dolomite from Rolling River, forwarded by Messrs. Fifield. Col. Mus. and Lab. 20th Ann. Rep., p. 42. Lab. No. 3940

Concerning the marble on Drummond's Run, Dr. Henderson reports that it is on the north-west side of the Wangapeka Valley, nearly opposite the "Blue Rocks," and is readily accessible from the road. In this locality a small stream has formed a large talus-cone, of which the individual blocks are largely marble. These appear to be of uniform composition, and a general sample taken from them yielded on analysis 94·25 per cent. of calcium carbonate (No. 6 of table above).

The "Blue Rocks" is a bluff of Tertiary limestone on the right bank of the Wangapeka, four miles above its confluence with the Motueka. Here, however, the stone is rather arenaceous, and decidedly inferior to the marble of Drummond's Run and that of the broad belt west of the Wangapeka River, with which the Drummond's Run marble is associated.

The following four analyses of Wangapeka limestone are quoted by B. C. Aston, but it is not possible to refer them to a definite locality or to say whether they represent Palæozoic or Tertiary rocks. The first two, however, are probably analyses of marble.

	(1)	(2)	(3)	(4)
Matter insoluble in acid	1·60	0·56	6·04	26·22
Alumina and iron oxides..	2·56	0·07	1·32	4·76
Calcium carbonate	95·67	99·37	85·36	68·92
	99·83	100·00	92·72	99·90
Quicklime (CaO) in calcined stone (per cent.)	93	99	86	55

Reference.—Aston, B. C., Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 329. Analyst's numbers, J 228–31. Date, 1909.

Dr. Henderson reports that a large deposit of high-grade Tertiary limestone occurs on a scenic reserve about a mile west from Kaka Railway-station (fifty-three miles from Nelson). The stone extends northward as a bare ridge, perhaps 200 ft. high, into Mr. Ellis's property, through which access is most easily gained. The beds are several hundred feet thick, strike nearly north and south, and have a steep easterly dip. The limestone is hard and compact. A general sample taken along the ridge mentioned above analysed as follows :—

	Per Cent.
Matter insoluble in acid	2·76
Lime (CaO)	53·76
Moisture lost at 100° C.	0·16
Calcium carbonate equivalent to lime	96·00
Quicklime (CaO) in calcined stone	93·3

Reference.—Dom. Lab. 50th Ann. Rep., 1917, p. 21. Original Lab. No. 1584 ; published No. 1578/7.

Lenticular bands of Permo-Carboniferous or "Maitai" limestone occur at intervals in the mountains bordering Waimea County on the east from Croixelles* south-westwards to Ben Nevis, and perhaps farther south. According to McKay this limestone is strongly developed on the south side of Croixelles Harbour (C.–10, 1901, p. 5). It has its chief development in the Maitai Valley and Dun Mountain district, east of Nelson, where, according to E. H. Davis, it attains a thickness of 2,000 ft. A large lens begins several miles north of the upper Maitai River, and extends south-west to a point half a mile south of the north branch of that stream, where it is apparently cut off by a huge intrusion of ultra-basic igneous rock (now a serpentine). This band has a maximum width of nearly half a mile. It dips steeply to the north-west. Another band of limestone begins a mile to the south-west, and extends continuously for nine miles and a half to the south-west. It passes over Wooded Peak, and forms conspicuous cliffs in the Roding, United, and Champion valleys. It is seen in Hacket Creek, but ends before reaching the Serpentine River.

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* Spelt "Croisilles" on some maps.

A narrow band of limestone extends from Goat Hill for more than two miles to the south-west, and reaches the south side of the Lee River. A small lens outcrops about three-quarters of a mile west of Goat Hill. Another long narrow band of limestone passes through the lower valley of the Roding River, and ends south-west of the Roding and Wairoa junction. Limestone again appears between five and six miles to the south-west of this junction, at or near Sellen's old homestead, Wairoa Gorge, south of Wakefield. There is a small lens of limestone between Lankow and Malcolm creeks, a mile and a half south-west of Hope. The farthest south recorded outcrops of the Maitai limestone are on Little Ben Nevis, in the north-west part of Rintoul Survey District, and on Gordon's Knob, thirteen miles to the south-south-west.

The Maitai limestone is normally a close-grained compact rock varying from blue-grey to nearly white in colour. Dark specimens are usually less pure than the lighter-coloured material. Examination under the microscope shows that it is largely composed of fragments of prismatic shells, which at one time were thought by some geologists to represent the remains of a species of *Inoceramus,* and therefore to indicate a Middle Mesozoic age for the limestone. C. T. Trechmann, however, has shown that the prismatic-shell fragments belong to a species of *Aphanaia,* a genus that occurs in the Permo-Carboniferous of New South Wales. In addition to this fact, sufficient other fossil evidence has been obtained to prove the Permo-Carboniferous age of the Maitai limestone and associated beds, so that one of the vexed questions of New Zealand geology has been set at rest, it is hoped, for ever.

Tertiary limestone outcrops for a short distance in O'Brien Creek, 4 chains above Glen Bridge. Another and larger exposure occurs on the foothills between O'Brien and Poor Man creeks. The limestone at these two places is composed of broken shells together with a few sea-urchin spines and a little grit, sand, and clay. Other outcrops of similar limestone may occur to the south-west.

Most or perhaps all of the following analyses of limestone from various localities in the eastern part of Waimea County represent samples of Maitai or Permo-Carboniferous limestone. The analyses are arranged in two groups, the first of which contains analyses made prior to 1910, with the exception of those representing samples collected by the Geological Survey, which are placed in the second group.

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid ..	10·2	10·14	3·14	8·18	1·03	1·48
Alumina	4·4	0·12	1·42	0·46	1·77	0·77
Iron oxides		Trace		Trace		
Calcium carbonate ..	83·4	87·15	91·73	88·20	97·20	95·70
Magnesium carbonate, &c. ..	1·3	2·49	3·47	2·95	..	..
Water, organic matter, &c. ..	0·7	0·10	0·24	0·21	..	..
	100·0	100·00	100·00	100·00	100·00	97·95
Quicklime (CaO) in calcined stone, per cent. (Aston and others)	75·4	81·0	89·2	83·2	96	94

	(7)	(8)	(9)	(10)	(11)	(12)
Matter insoluble in acid ..	4·60	6·93	0·59	3·50	6·85	3·41
Alumina	3·77	2·24	0·45	0·69	2·15	3·00
Iron oxides						
Calcium carbonate ..	91·63	89·00	95·86	94·56	86·00	90·14
Magnesium carbonate, &c. ..	..	1·18	0·10	..	0·80	0·40
Water, organic matter, &c. ..	..	..	..	..	..	..
	100·00	99·35	97·00	98·75	95·80	96·95
Quicklime (CaO) in calcined stone, per cent. (Aston and others)	88	84	96	91	78·0	83·9

References.—(1) Bituminous limestone from Sellen's (not Sullen's), Wairoa Gorge, collected by Mr. Alex. McKay. Col. Mus. and Lab. 13th Ann. Rep., 1878, p. 23. Lab. No. 2064. Bituminous substances amount to 0·7 per cent.

(2) Crystalline limestone from Limestone Bluff, Champion lead, forwarded by Mr. A. D. Bayfeild. Col. Mus. and Lab. 20th Ann. Rep., 1886, p. 41. Lab. No. 3919.

(3) Solid dull-grey limestone from Croixelles, forwarded by Mr. J. B. Blaine. Col. Lab. 29th Ann. Rep., 1895, p. 11. Lab. No. 6641/4.

(4) White coherent limestone from vicinity of Nelson, forwarded by the Locomotive Superintendent, Railway Department. Col. Lab. 34th Ann. Rep., 1901, p. 12. Lab. No. 8716.

(5) to (8) Nelson. Aston, B. C., Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 329. Analyst's Nos. H 182, 183, 184, and J 84. Dates, 1907 and 1908.

(9) (10) Belgrove. Same references as Nos. 3 to 6. Analyst's Nos. H 654 and 655. Date, 1907.

(11) (12) From Quail Valley, Belgrove, forwarded by Mr. George E. Field. Dom. Lab. 43rd Ann. Rep., 1910, p. 11. Lab. Nos. 2228/1, 2.

	(1)	(2)	(3)	(4)	(5)	(6)
Silica (SiO_2)	3·30	3·95	6·60	14·15	15·50	..
Ferric oxide (Fe_2O_3) ..	0·80	1·73	2·30	5·21	5·89	..
Alumina (Al_2O_3)	1·35				1·28	..
Magnesia (MgO)	0·70	0·30	0·80	0·90	1·20	..
Lime (CaO)	52·40	90·91	87·73	77·22	41·05	90·0
Carbonic anhydride (CO_2) ..	41·14				32·23	
Moisture	0·15	2·05	1·35	0·45	0·85	..
Organic matter	Nil					
Alkalies and undetermined ..	0·16	1·06	1·22	2·07	2·00	..
	100·00	100·00	100·00	100·00	100·00	..
Quicklime (CaO) in calcined stone (per cent.) ..	89·3	87·9	81·8	65·9	61·3	83·4

References.—(1) General sample from outcrop on the ridge between the Miner and Roding rivers, near the head of Stratford Creek. Dom. Lab. 43rd Ann. Rep., 1909, p. 11; and N.Z. Geol. Surv. Bull. No. 12, 1911, p. 18. Lab. No. 2571/1.

(2) Sample from limestone cliff on the Champion track. Same references as No. 1. Lab. No. 2253/5.

(3) Represents a specimen from south end, and (4) a specimen from north end of limestone cliff on the United Copper Company's tramway. Same references as No. 1. Lab. Nos. 2253/10, 11.

(5) Tertiary limestone from O'Brien Creek. Dom. Lab. 43rd Ann. Rep., 1909, p. 11 (recorded as from Enner Glynn Creek); and N.Z. Geol. Surv. Bull. No. 12, 1911, p. 66. Lab. No. 2571/2.

(6) From Brightwater, forwarded by Mr. A. W. Bell. Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. No. G 382.

Several travertine deposits are found in the Dun Mountain district. One of these is on the north bank of Miner Stream, a quarter of a mile above its junction with the Hacket. A calcareous spring issuing on the hillside 300 ft. above the valley-floor has coated an area of several acres with travertine to an average depth of at least

20 ft. Similar deposits are found in Mill Creek, a tributary of the Maitai River, and in the main branch of the Teal River. In all cases the carbonate of lime deposited has been derived from belts of Maitai limestone.

Summary of Limestone Resources.

From what has been stated on the preceding pages it will be perceived that Waimea County possesses great deposits of limestone and marble, which in most places are of great purity. Unfortunately many of the limestone areas are difficult of access, or are situated where they are not of much value for other than local use. The most conveniently situated deposits are the marbles of the lower Riwaka Valley, which can supply the rich alluvial land of the lower Motueka Valley and the fruit lands of the Moutere Hills with lime. The Wangapeka district can be supplied from the marble on Drummond's land.

The Tertiary limestone west of the Kaka Railway-station is nearer the railway than any other deposit of importance in Waimea County. At the time of writing it is about to be developed, and probably lime-works will be in operation before this report is published.

The nearest limestones to the Waimea Plain are the Tertiary limestones of O'Brien and Poor Man creeks, and the Permo-Carboniferous limestones at Lankow Creek, and at the junction of the Roding and Wairoa rivers. Only the last-named deposit is likely to be worth developing. Limestone is seen on both sides of the united streams (now called the Waimea River), at a point two miles and a quarter south-east of Brightwater Railway-station. The locality has not been visited by any of the present members of the Geological Survey staff, and the writers are unable to say whether quarrying on a large scale is practicable or not.

Means of Transport.

Waimea County possesses the important port of Nelson and a number of other harbours, some of which, such as Croixelles, are not well situated for trading purposes. Motueka now has a good harbour for small vessels, and there are several other points on the shores of Blind Bay where small steamers and scows may load or unload. A railway runs from Nelson to Glenhope, in the extreme south of the county. The Waimea and Motueka valley-flats are well roaded, but the hilly districts are naturally less fortunate in this respect, and in the highland areas only bridle and foot tracks have been made. The road over the Pikikiruna Range, however, is an exception to this statement. Considering its mountainous nature, Waimea County may be said to have good internal communications.

Literature.

That part of Waimea County contained in Waimea and Maungatapu survey districts has been geologically surveyed in detail, and the results will be found in N.Z. Geol. Surv. Bull. No. 12, 1911, "The Geology of the Dun Mountain Subdivision, Nelson," by J. M. Bell, E. de C. Clarke, and P. Marshall. The list of literature on pages 6–9 of that bulletin gives the titles of most of the reports and papers dealing with the geology of Waimea County.

The reports and papers indicated in the following list are either supplementary to the list in Bull. No. 12, or deal with areas wholly outside the Dun Mountain Subdivision:—

Rep. Geol. Explor., No. 4, 1868, pp. 27–28; No. 19, 1888, pp. xxxix–xl, 74–78, 90–92; 1890, No. 20, part of pp. lvii–lviii, pp. 69–74, part of pp. 186–243; No. 21, 1892, pp. 20–21, 38–43 (marble of Pikikiruna Range), 168–70 (geology of county summarized).

"Reports on the Coalfields of New Zealand," Parl. Paper E.–10, 1873, p. 2.

Parl. Paper C.–11, 1896 (bound in Mines Rep.), pp. 27–31. Parl. Paper C.–10, 1901 (bound in Mines Rep.), pp. 5–6.

Trans. N.Z. Inst., vol. 43, 1911, part of pp. 297–315.

7th Ann. Rep. N.Z. Geol. Surv., part of Parl Paper C.–2, 1913, pp. 129–30, 131–33. 9th Ann. Rep., part of Parl. Paper C.–2, 1915, pp. 82–86.

4. SOUNDS COUNTY.

The rocks of Sounds County consist almost entirely of Palæozoic and Early Mesozoic schists, greywackes, and argillites. In D'Urville Island a belt of serpentine and Permo-Carboniferous limestone, as mentioned below, is probably also present. The county has very little flat or arable land, and is therefore mainly a pastoral district, which at present requires very little lime.

The only reported occurrence of limestone in Sounds County is on D'Urville Island, from which a sample of fine-grained marble, containing 96·42 per cent. of calcium carbonate, was forwarded to the Colonial Laboratory in 1885 by the Hon. Captain Kenny. (Col. Mus. and Lab. 21st Ann. Rep., 1886, p. 36. Lab. No. 4111.) The specimen was probably from a northern continuation of the beds of Permo-Carboniferous limestone occurring in the mountains eastward of Nelson, and known to extend northward on the mainland as far as Croixelles.*

Means of Transport, &c.

The deep indentations of Pelorus and Queen Charlotte sounds with their numerous arms give Sounds County splendid sea communications. The district is too hilly and broken to be well roaded, but the arms of the sea compensate for this, and in practice take the place of roads.

Literature.

The following reports, in whole or in part, specially refer to the geology of Sounds County :—

Rep. of Geol. Explor., No. 7, 1872, pp. 125–29; No. 8, 1877, pp. 30–33; No. 9, 1877, pp. 2–8; No. 11, 1878, pp. 1–5; No. 12, 1879, pp. 30–36, 55–59, 86–97; No. 17, 1886, pp. 10–13; No. 20, 1890, pp. xxx–xxxi, 36–44, 60–63, 85–185; No. 21, 1892, pp. xxix–xxxiii, lxxi, 163 (only four lines refer to Sounds County as now constituted).

Parl. Paper C.–6, 1894 (bound in Mines Rep.), p. 8; Parl. Paper C.–9, 1899 (bound in Mines Rep.), pp. 31–33.

5. MARLBOROUGH COUNTY.

Marlborough County is composed mainly of Palæozoic and old Mesozoic schists, argillites, and greywackes. There are small areas of Tertiary rocks, and the lower Wairau Valley contains a fertile and extensive plain, of which Blenheim is the centre. Elsewhere the areas of flat land are small.

Very little calcareous material is to be found in Marlborough County. The only known localities are—(1) in the vicinity of Picton, (2) fourteen or fifteen miles south-west of Blenheim, and (3) near Taylor's Pass. The last-mentioned occurrence is described on page 197, under "Awatere County."

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* B. C. Aston reports a specimen of limestone from Waitaria Bay (Queen Charlotte Sound) with 96·5 per cent. carbonate of lime (Jour. Agric., vol. 17, No. 2, Aug. 1918, p. 98).

At Shakespeare Bay, near Picton, is a series of Early Tertiary beds containing conglomerates which have a calcareous matrix, and in places pass into impure limestone. The beds are highly disturbed, and dip at all angles and in all directions. At the cemetery near the head of a creek falling into Picton Bay are considerable masses of limestone, and a similar rock appears on the peninsula separating Picton and Shakespeare bays. At The Elevation, one mile and a half south-west of Picton, calcareous claystone, probably of Miocene age, occurs, and on the south side of the saddle similar material is exposed over a width of from 250 yards to 300 yards. (Rep. of Geol. Explor. No. 14, 1882, pp. 110, 111.) Analyses of the Picton limestone are—

	(1)	(2)
Silica	7·51	6·62
Alumina	2·67	2·16
Iron oxides	0·88	1·04
Lime	49·00	49·86
Magnesia	0·63	0·71
Carbonic anhydride	38·50	39·18
	99·19	99·57
Calcium carbonate, by addition of lime and carbonic anhydride (per cent.)	87·50	89·04

Reference.—From Picton Bay, forwarded by the Under-Secretary, Mines Department, per Mr. Alex. McKay, Government Geologist. Dom. Lab. 42nd Ann. Rep., 1909, p. 20. Lab. Nos. 1668/1, 2.

A sample of close-grained calcareous sandstone from the Waitohi Valley, near Picton, forwarded in 1904 by the Waitohi Valley Mining Company to the Colonial Laboratory, had the following composition:—

	Per Cent.
Organic matter and water	8·0
Silica and silicates insoluble in HCl	51·7
Calcium carbonate	36·4

Reference.—Col. Lab. 38th Ann. Rep., 1905, p. 8. Lab. No. 9680.

The following three analyses probably represent calcareous claystones from the same locality:—

	(1)	(2)	(3)
Silica	..	40·90	44·30
Alumina	..	12·50	13·90
Iron oxides	..	3·60	4·90
Lime	16·99	18·49	15·51
Magnesia	..	1·10	1·70
Carbonic anhydride	13·35	14·53	12·19
Moisture and organic matter	..	5·30	5·60
	..	96·42	98·10
Calcium carbonate by addition of CaO and CO_2 (per cent.)	30·34	33·02	27·70

Reference.—Dom. Lab. 42nd Ann. Rep., 1909, p. 21. Lab. Nos. 1979/1 and 2017/1, 2.

Mr. A. P. Seymour, of Picton (formerly Provincial Superintendent, &c.), has informed one of the writers that limestone covers a considerable area at the head of Pig Gully, a tributary of the Omaka River. The locality is quite fifteen miles south-west of Blenheim as the crow flies. The name "Castle Hill," south of Pig Gully, perhaps refers to weather-worn limestone outcrops. The limestone probably extends to the crest of the dividing-range between the Wairau and Awatere rivers, and may continue into the valleys of Blairich and Black-birch creeks (see p. 202). Westward, on or near a large tributary of the Omaka River, less than half a mile from the junction of the streams, is a limestone cave.

The following five analyses of limestone from the neighbourhood of Blenheim and the Wairau Valley have been made. In no case is the exact locality of the material known to the writers.

	(1)	(2)	(3)	(4)	(5)
Calcium carbonate	74·2	90·67	83·64	91·35	50·30
Magnesium carbonate	..	2·16	2·69	0·02	5·02
Alumina and iron oxides	..	4·22	1·84		1·68
Silica, or matter insoluble in acid	..	2·41	9·63	7·85	43·00
Sulphuretted hydrogen	..	..	0·34	.	..
Water and organic matter	..	..	1·86	..	..
	..	99·46	100·00	99·22	100·00

References.—(1) From Washdyke Creek, Marlborough, forwarded by Mr. B. Chaytor. Col. Mus. and Lab. 14th Ann. Rep., 1879, p. 25.

(2) Vesicular limestone, occurring seven miles from Blenheim, forwarded by Mr. Dodson, M.H.R. Col. Mus. and Lab. 22nd Ann. Rep., 1887, p. 41. Lab. No. 4550.

(3) Dark-coloured massive limestone from Wairau Valley, forwarded by Mr. Tyree. Col. Lab. 32nd Ann. Rep., 1899, p. 7. Lab. No. 8136. The presence of sulphuretted hydrogen in this rock is noteworthy. This is perhaps a Permo-Carboniferous limestone. (See also under the heading of "Awatere County," p. 197.)

(4) Near Blenheim, forwarded by Mr. H. D. Vavasour. Dom. Lab. 46th Ann. Rep., 1913, p. 20. Lab. No. C 935. "This is a good limestone, and would yield a 'burnt' lime containing about 80 per cent. of quicklime (CaO)."

(5) From Parikawa, Blenheim, forwarded by Moore and Smythe, per Fields Division, Department of Agriculture. Dom. Lab. 48th Ann. Rep., 1915, pp. 21, 38. Lab. No. E 966. The locality of Parikawa (or Pirikawa, as it is spelt on page 38 of the Laboratory Report) is unknown to the writers. It may, however, be Parikawakawa, which is situated on the coast a few miles south of Kekerangu, and therefore is in Awatere County.

Summary of Lime Resources and of Means of Transport.

Marlborough County apparently has very little limestone conveniently situated for being worked. The limestone near Picton, though it yields good samples, is probably only in small quantity, and hardly worth developing. Very little reliable information is to hand concerning the limestone that occurs fifteen miles south-west of Blenheim, and possibly nearer, so that the writers are unable to say whether this can be developed in any way. At present it appears that the Wairau farmers will have to obtain pulverized limestone from the Cape Campbell or Ward district in Awatere County (see p. 198, *et seq.*). A railway runs from Picton southward through Blenheim to Wharanui in Awatere County, and will ultimately be continued till it connects with the Canterbury railways. From Ward to Blenheim by rail is only thirty miles, and to the port of Picton, on Queen Charlotte Sound, another eighteen miles. The more settled parts of Marlborough possess good or fairly good roads, but a considerable area is mountainous and almost unroadable. The heads of Pelorus and Queen Charlotte sounds, both magnificent natural harbours, are in Marlborough County. Another good harbour, at present little used, is Port Underwood. Small vessels can enter the Wairau River and proceed up the Omaka branch as far as Blenheim. The county thus has good sea communications.

Literature.

The more important references to the geology and structure of Marlborough County are contained in the following reports:—

Rep. of Geol. Explor., No. 4, 1868, pp. 34–36; No. 7, 1872, pp. 119–25; No. 8, 1877, pp. 27–58; No. 9, 1877, pp. 32–35; No. 12, 1879, pp. 30–36, 86–100; No. 13, 1881, pp. 147–49; No. 14, 1882, pp. xiii–xvi, 106–15; No. 20, 1890, pp. xxxvi–liv, 36–44, 85–185; No. 21, 1892, parts of pp. 1–28, 158, 163; No. 22, 1894, pp. xxx–xxxiii.

9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, pp. 81–82.

Trans. N.Z. Inst., vol. 45, 1913, pp. 316–22 (C. A. Cotton).

6. Buller County.

Buller County consists of a long strip of country on the west coast of the South Island, extending from Kohaihai Point, mounts Domett, Cobb, and Arthur, to the Punakaiki River.* Its extreme length, from Mount Cobb to the source of the Punakaiki, is almost 100 miles. The rocks of the county comprise Palæozoic gneisses, schists, greywackes, and argillites, much intruded by granite and other igneous rocks, Eocene and Miocene conglomerates, grits, sandstones, limestone, and calcareous claystones, Pleistocene and Recent gravels, sands, &c.

The Eocene strata contain valuable seams of bituminous coal, best developed north-east of Westport, and the Miocene beds contain a great deal of brown coal. Gold-bearing lodes occur in the Palæozoic rocks, while the Quaternary gravels and sands are in many places highly auriferous.

Ordovician marble is seen at Mount Arthur and on the range to the south (see p. 170). The locality is remote, and has its natural outlet into Waimea County, so that no consideration need be given to it from the Buller County point of view. Possibly also marble appears in the country between Mount Arthur and Mount Cobb, but this district is even more remote and difficult of access than Mount Arthur. McKay mentions the occurrence of limestone west of Mount Peel, which, he believes, is either of Devonian or of Carboniferous age (Rep. Geol. Explor., No. 12, 1879, pp. 128–29), and in the latter case may be the equivalent of the Maitai limestone.

Limestone of Tertiary age is abundant in Buller County. Some is Eocene, but most is of Miocene age. A large area of limestone extends from the watershed between the Takaka and Leslie rivers down the Leslie Valley to Karamea Bend, and thence for some miles up the Karamea River. There is also limestone near the heads of the Karamea and Mokihinui rivers (Hector, Rep. Geol. Explor., No. 16, 1884, p. xvii, and No. 21, 1892, p. xl). The following section is one to which Hector attaches much importance, and partly for that reason it is reproduced here:—

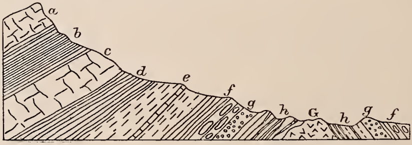

Fig. 5.—Section at Source of Karamea River. (After Hector.)

a. Grey concretionary limestone. *b*. Grey marls, with *Pecten pleuronectes*. *c*. White splintery limestone. *d*. Fucoidal greensand. *e*. Chalk-marls, with bands of chert. *f*. Dark greensand and concretionary sandstone. *g*. Brown grit and sandstone, with *Cardium brunneri*. *h*. Brown sandstone, with fossil plants and coal-seams. *G*. Granite. The section represents a vertical height of 2,700 ft.

The district westward of the localities last mentioned has been examined in detail by E. J. H. Webb, who states that argillaceous limestones of Miocene age are widely distributed through Kongahu and Otumahana survey districts (N.Z. Geol. Surv. Bull. No. 11, 1910, p. 19). A well-defined band of limestone from 20ft. to 50 ft. thick occurs in a higher horizon, and extends for many miles. It is a shallow-water deposit, and is generally of a flaggy nature, with the individual bands or beds usually from 4 in. to 6 in. thick. As a rule it is shelly and arenaceous or gritty, but in some localities is argillaceous or glauconitic, whilst in others it passes into calcareous grit or conglomerate. Portions are of excellent quality. These are generally bluish or nearly white in colour, and of crystalline or semi-crystalline appearance. On pages 38 to 40 of the bulletin mentioned above Webb describes the limestones of the Mount Radiant Subdivision in some detail. He cites no less than eighteen nearly complete analyses, and six determinations of calcium carbonate. An analysis of fine-grained calcareous sandstone or ".papa" from Granite Creek is given on page 21. The analyses are too numerous to quote in full, but they are included in the list on a later page. Webb's remarks may be summarized as follows:—

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* This is the boundary shown on the maps used by the writers. For many years Grey County claimed the strip of country between the Punakaiki and the Porarari rivers, but the dispute, the writers understand, has been settled in favour of Buller County. The names Punakaiki and Porarari, mentioned above, are spelt in various ways

(1.) In the Kakapo River, a tributary of the Karamea, a band of flaggy semi-crystalline limestone about 75 ft. thick is exposed. It is generally of high quality, but gritty in places. A general sample contained 99·08 per cent. of calcium carbonate.

(2.) In Huia Stream, a tributary of the Kakapo, the high-grade limestone (? near its head) has a maximum thickness of 20 ft., and contains 98·05 per cent. of calcium carbonate. A rather gritty limestone, 20 ft. thick, seen in the most southerly left or western branch of Huia Stream, yielded a sample containing 91·50 per cent. of calcium carbonate. A sample of argillaceous arenaceous limestone contained about 72 per cent. of calcium carbonate.

(3.) Rather indefinite outcrops of limestone at elevations of about 1,640 ft. in the first and third left (eastern) branches of Lawrence Stream, a tributary of the Little Wanganui, showed thicknesses varying between 10 ft. and 20 ft. Samples contained 94·96 per cent. and 96·96 per cent. of calcium carbonate.

(4.) A poor outcrop of slightly dolomitic semi-crystalline limestone outcrops in Drain Creek (a small stream joining the Little Wanganui south-west of Mount Scarlett). The sample analysed contained 89·41 per cent. of calcium carbonate and 7·18 per cent. of magnesium carbonate.

(5.) At the base of Black Rat Mountain flaggy limestone is well exposed in the track-cutting on the north bank of the river.* It outcrops also on the south side of the river, where it is seen to have a thickness of about 100 ft. Webb says that the limestone is of very variable character, some being high grade, some arenaceous and gritty, some glauconitic, and some calcareous grit or conglomerate. Two samples picked from the best zone, 20 ft. thick, contained 96·70 and 96·84 per cent. of calcium carbonate. Three general samples from the whole zone contained 90·92, 93·00, and 94·03 per cent. of calcium carbonate—results that seem to indicate the limestone as a whole to be of better quality than Webb supposed.

(6.) A sample of highly calcareous, rather argillaceous sandstone from the Upper Mokihinui River contained 46·4 per cent. of calcium carbonate.

(7.) A sample of arenaceous limestone from the head of Maori Gully Stream contained 70·1 per cent. of calcium carbonate. Another sample from a point two miles lower down Maori Gully contained 69·0 per cent. of calcium carbonate. Full analyses are quoted by Webb.

(8.) Three samples of limestone from the New Inland Road (presumably from points north of Corbyvale) yielded 81·7, 68·2, and 59·3 per cent. of calcium carbonate.

(9.) A sample of arenaceous limestone from Falls Creek contained 61·8 per cent. of calcium carbonate.

(10.) Some miles up Glass-eye Creek the band of fairly good limestone described by Webb crosses the stream at two places. At one of these the lower half of the limestone band was found to contain 87·8 per cent. of calcium carbonate, and the upper half 91·0 per cent.

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* Little Wanganui.

(11.) At Little Wanganui Head a 15 in. band of limestone in a low horizon of the Miocene rocks yielded a sample containing 86·6 per cent. of calcium carbonate.

(12.) A sample of arenaceous limestone from the beach near the south end of Big Hill Track contained 59·3 per cent. of calcium carbonate.

Most of the localities where Webb obtained his samples of limestone are definitely fixed by his descriptions and his geological map of Kongahu and Otumahana survey districts. The other localities may be ascertained by consulting his notebooks, which have been preserved in the Geological Survey Office.

Limestone outcrops somewhat extensively near the main fork of the Mokihinui River, above Mokihinui Reefs, but the locality has not been examined by any geologist.

The greater part of Buller County south of the area surveyed by Webb has been examined in detail by P. G. Morgan, J. A. Bartrum, and J. Henderson, so that tolerably full information concerning its limestones can be obtained.

South of Corbyvale argillaceous limestone outcrops on the New Inland Road from Seddonville to Karamea. Southward it contains many arenaceous or gritty bands, and forms a prominent cliff several hundred feet high. A representative sample collected by P. G. Morgan early in 1911 contained 55·4 per cent. of calcium carbonate. The complete analysis is quoted in N.Z. Geol. Surv. Bull. No. 17, 1915, p. 128. Highly calcareous claystone or argillaceous limestone outcrops in the valleys of Six-mile and Three-mile creeks, and also forms the upper part of the cliff on the coast-line between the mouths of these two streams. The same type of rock forms the conspicuous cliffs at Gentle Annie and Kongahu points.

Towards the head of Fletcher Brook, a branch of Charming Creek, somewhat flaggy limestone of Eocene age is seen to form low cliffs on and near the stream. It dips at 12° to 15° to the south-west, and is overlain by more or less irregular layers of mudstone and glauconitic sandstone. It is here of good quality, and well adapted for the manufacture of lime or cement, but the area over which high-grade rock outcrops is small, and the locality is many miles from Westport, which is practically the nearest shipping-point. The locality, however, is near a timber tram-line, which leads to the rail-head at Mokihinui Mine, less than three miles away. It is possible, therefore, that the stone could advantageously be pulverized or calcined for use on the Seddonville flats and the arable land along the coast-line from Mokihinui mouth (Kynnersley or Waimarie) southwards. A sample of the limestone collected by P. G. Morgan in February, 1911, contained 90·7 per cent. of calcium carbonate (or 93·4 per cent. if $CaCO_3$ is calculated from the lime content). The complete analysis is given in N.Z. Geol. Surv. Bull. No. 17, p. 128, where also various other analyses of samples from specified localities collected by the writers of that bulletin will be found.

South of Fletcher Brook impure limestone outcrops in St. Andrew and St. David streams, perhaps in different horizons. In composition it varies from argillaceous limestone to calcareous claystone and arenaceous limestone. A sample from St. Andrew Stream collected by P. G. Morgan in March, 1911, contained 54·2 per cent. of calcium carbonate, 3·51 per cent. of magnesium carbonate, and 0·06 per cent. of phosphoric anhydride. Somewhat better stone outcrops in the same stream a few chains higher up, and about three-quarters of a mile in a straight line above the crossing-point of the track from Mokihinui Mine to the Mackley Valley.

At the north end of the bridge over the Buller River north-west of Lyell thick and fairly good limestone, standing almost on edge and striking east of north, forms a cliff in which roadways have been cut for several chains. The limestone here is of bluish colour, and contains somewhat numerous grains and small angular pieces of other rocks. An analysis of a general sample collected by P. G. Morgan in 1913 yielded 90·2 per cent. of calcium carbonate. Southward argillaceous limestone outcrops on and near the main road towards Three-channel Flat. The stone as exposed is yellowish-white and argillaceous or sandy. It dips steeply, as a rule, to the north of west.

On the track to Boundary Peak poor limestone and calcareous sandstone outcrop in several places. There is some sandy limestone and calcareous sandstone in a hill south-west of Three-channel Flat, which is near Inangahua County boundary. About two miles up New Creek, a small stream joining the Buller below the Lyell Bridge, light-coloured argillaceous limestone outcrops on the west side of the stream (not far below Roger Creek junction). It dips at angles of 20° to 50° to the westward. Two miles up Pensini Creek, which joins the Buller from the west not far below New Creek, similar limestone is exposed for some chains. It is near a fault, and the dip varies from 35° to 88° to the north of west. Two miles to the north-west there is limestone on the ridge between Slug and Blue Duck creeks. In this locality the limestone has been mostly removed by erosion, and probably does not cover a large area. Some of it appears to be of fair quality. The locality, however, is remote, and very difficult of access. Limestone forms part of Mount Courtney, on the north side of the Buller west of Inangahua Junction, and extends over some of the country to the northward. It also forms a prominent cliff on the north bank of the Buller south of Mount Courtney. There is also a small area of limestone near the north end of the suspension bridge across the Buller near Inangahua Junction.

Argillaceous limestone appears on or near the south bank of the Buller from Rocklands eastward to Inangahua Junction, and thence extends in a wide belt south-south-westward for at least ten miles. Part of this area is in Inangahua County. South of McMurray Creek the belt is narrow, but can be traced for over three miles farther to Te Wharau or Stony River. This part of the belt (which is wholly in Inangahua County) shows a prominent scarp, directed to the south-east. Within the broader part of the belt are Rose Mount (close to Inangahua Junction), Berlin's or Burley's Bluff, and part of the watershed of Nada Creek, a right branch of the Blackwater River that joins the Buller from the south a few miles west of Inangahua Junction. All these localities are close to Inangahua County boundary. Most of the limestone in this belt is argillaceous and low grade, but there is quite a good limestone near the junction of Nada Creek and its branch Lily Creek. The locality, however, is hopelessly remote, and will certainly not be developed by the present generation.

There are some important limestone exposures in the coastal region south of the Buller. The first to be mentioned, however, is of no consequence. It consists of an outcrop of highly calcareous claystone or argillaceous limestone in Omanu or Back Creek just below the crossing of the Loop-line Road, which connects the Lower Buller Gorge Road with the road from Westport to Addison's.

The best limestone in Buller County, and also that most favourably situated for the manufacture of lime and cement, occurs near Cape Foulwind. On the beach near Cape Foulwind there is only 15 ft. or perhaps 20 ft. of stone sufficiently pure to be called limestone, but it is underlain by a considerable thickness of ferruginous highly calcareous grit with thin bands of limestone. Blue argillaceous fine-grained sandstone and calcareous sandy claystone overlie the limestone. The beds dip at 10° to 14° to the south of east. In the Harbour Board's quarry a quarter of a mile to the south-east a 50 ft. face of excellent limestone is exposed. Boring has shown that this is underlain by another 30 ft. of almost equally good stone, below which ferruginous calcareous grit similar to that on the beach appears. Limestone is continuously exposed from here to the southward towards Tauranga Bay for a mile, and the average width of the outcrop is at least 10 chains. It therefore covers an area of 80 acres, and the amount of workable stone on a conservative basis is not less than 6,000,000 tons. At the quarry the bedding appears to be almost flat, but elsewhere the limestone has a dip of about 10° to the south-east. The limestone was at one time quarried for the harbour-works at Westport, and in later years has been worked intermittently for making lime in a kiln built close to the Harbour Board quarry.

A sample of the limestone outcropping on the beach collected by P. G. Morgan in 1912 contained 87·4 per cent of calcium carbonate. A sample of the ferruginous calcareous grit that underlies contained 61·25 per cent. of calcium carbonate. Samples from the quarry, from the upper part of a bore put down in the quarry, and from Fox's farm to the southward, contained 94·0, 89·2, and 96·1 per cent. of carbonate of lime, and 1·72, 3·00, and 0·63 per cent. of magnesium carbonate. The drillings from the lower part of the quarry bore contained about 71·3 per cent. of calcium carbonate and 2·94 per cent. of magnesium carbonate. References to the full analyses are given later, where also other analyses are quoted. The Cape Foulwind limestone is light-coloured, and the best stone is highly crystalline in appearance. On Fox's farm there are several caves.

The Cape Foulwind limestone continues southward of Tauranga Bay, but is completely hidden by Pleistocene and Recent gravels for nearly six miles. A small patch appears on the north bank of the Totara River, a mile from the sea-coast. Here it dips gently to the east. Other patches of flaggy limestone occur on the north and south banks of the Little Totara, about the same distance inland. The latter patch is conveniently situated for working beside the main road, and appears to be of fair quality. The limestone dips very gently to the east, and is probably at least 200 ft. thick.

East of Charleston thick limestone forms cliffs on both banks of the Waitakere or Nile River, at points two miles or more from the sea. It is also seen in its right-hand branch, the Awakari Stream. From this locality limestone extends in a wide belt to the southern boundary of the county, a distance of about fifteen miles. Prominent escarpments, in the north two miles from the coast, but farther south approaching the coast, extend from east of Charleston southward. There are prominent limestone cliffs in the valleys of Four-mile Creek, Fox River, Bullock Creek, Porarari River, Punakaiki River, &c. Calcareous rocks, which probably do not form part of the limestone horizon under description, appear on the coast at various points south of Fox River.

A platform has been cut by ancient sea-action in the limestone at the mouth of Limestone Creek, about two miles south of the Fox River. Four miles south of the Fox the great cliff of Te Miko, over 1,000 ft. high, is largely composed of calcareous sandstone and claystone belonging to a horizon below the limestone, which is, however, not far inland, and actually forms a high cliff at Cave Point, south of the Porarari River. Limestone also forms Razorback Point, south of the Punakaiki, and therefore outside Buller County and in Grey County. In this locality the limestone grades upwards into a white gritty calcareous sandstone.

The main limestone belt, east of Charleston and southwards, is from two to over three miles wide, but between the stream-valleys it is largely masked by gravels. The beds lie nearly flat or dip gently to the east. East of Charleston the limestone is thought to be from 300 ft. to 400 ft. thick. The quality is fair to good. In the Fox River the cliffs rise to heights of over 500 ft., and the limestone is certainly quite 600 ft. thick here and for six or seven miles to the south-south-west. Some of the limestone in the Fox Valley is of excellent quality, but no sampling has ever been done.

Analyses of Buller County Limestones.

For the sake of reference all available analyses of Buller County limestone not quoted *in extenso* in Geological Survey bulletins will be tabulated in the same way and with the same particulars as on previous pages. The samples analysed, as it happens, are all from Cape Foulwind, with one possible exception attributed to Buller County. The table will be followed by a tabulated list of the analyses quoted in

PLATE IX.

A. Cliffs of Calcareous Mudstone near Cape Foulwind.

B. Cobden Limestone: Quarry on South Side of Grey River.

Geological Survey bulletins, with references both to the bulletins and the Colonial or Dominion Laboratory reports in which the analyses appear.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Calcium carbonate ..	96·75	92·61	91·30	90·62	93·18	95·22	97·00	94·99
Magnesium carbonate ..			2·94	2·86	3·12	2·46	0·61	1·65
Alumina	..	..	1·81	1·64	..	0·63	0·24	1·56
Iron oxides	..	..			1·26	0·84		
Phosphoric anhydride ..	..	..	..	..	..	..	0·22	..
Matter insoluble in acid ..	..	..	3·61	3·47	2·03	0·64	1·31	1·16
Water, &c.	..	..	0·34	1·41	0·41	0·21	0·43	..
	..	..	100·00	100·00	100·00	100·00	99·81	99·36

References.—(1) (2) Limestones from Cape Foulwind, forwarded by the Director of the Geological Survey (Sir James Hector). Col. Mus. and Lab. 23rd Ann. Rep., 1889, p. 54. Lab. Nos. 4745 (*a*) (light-coloured stone) and 4745 (*b*) (dark-coloured).

(3) (4) Concretionary limestones from vicinity of Cape Foulwind, forwarded by Mr. C. Brown. Col. Mus. and Lab. 25th Ann. Rep., 1891, p. 57. Lab. Nos. 5343/1, 2.

(5) Rather soft limestone from Cape Foulwind, forwarded by Mr. R. H. J. Reeves. Col. Mus. and Lab. 27th Ann. Rep., 1893, p. 28. Lab. No. 6154/1.

(6) Limestone from Cape Foulwind, forwarded by Mr. James Jameson. Col. Lab. 33rd Ann. Rep., 1900, p. 10. Lab. No. 8460. "A capital limestone," fit for agricultural purposes (lime-burning) and for a building-stone.

(7) Limestone from Cape Foulwind, forwarded by Buller County Council. Dom. Lab. 48th Ann. Rep., 1915, p. 19. Lab. No. E 115. "When burnt it would yield a lime containing quicklime (CaO) 96·35 per cent. This is a limestone of good quality, suitable for agricultural and building purposes."

(8) Buller County. Aston, B. C., Jour. Agric., vol. 11, No. 4, Oct., 1915, p 329 Analyst's No. and date, K 143, 1909.

Limestone-analyses quoted in N.Z. Geol. Surv. Bull. No. 11.

Locality.	Page of Bulletin.	Collector's Number and Date.	Dominion Laboratory Report and Page.	Laboratory Number.
Little Wanganui River	39	42, 20/3/08	42nd, 1909, p. 21	1884/1
,, ...	39	43, 20/3/08	,,	1884/2
,, ...	39	44, 20/3/08	,,	1884/3
Granite Creek (marl)	21	45, 23/4/08	,,	1885
Drain Creek	38	76, 12/6/08	,,	1890
Little Wanganui River	39	64, 23/5/08	,,	1898/1
,, ...	39	65, 23/5/08	,,	1898/2
Head of Blacktopp Creek ..	39	111, 21/9/08	43rd, 1910, p. 11	2470/1
Lower left branch, Lawrence Creek	39	121, 24/9/08	,,	2470/2
Third left branch, Lawrence Creek	39	122, 24/9/08(?)	,,	2670/3
Huia Stream	39	124, 8/10/08	,,	2470/4
,, ...	39	125, 8/10/08	,,	2470/5
Third left branch, Huia Stream ..	39	128, 31/10/08	,,	2470/7
Kakapo River	39	127, 12/11/08	,,	2470/6
Station 41, Mokihinui River ..	40	142, 4/3/09	,,	2470/8
Station 7, head of Maori Gully ..	39	143, 15/3/09	,,	2470/9
Station 61, Maori Gully	39	144, 16/3/09	,,	2470/10
New Inland Road	39	155, 28/5/09	43rd, 1910, p. 12	62/1
,, ...	40	156, 22/6/09	,,	63/1
,, ...	40	158, 2/6/09	,,	63/2
Falls Creek	40	159, 10/6/09	,,	63/3
Beach, south end, Big Hill Track ..	40	170, 12/6/09	,,	63/4
Little Wanganui Head	39	163, 22/6/09	,,	62/2
Glass-eye Creek	39	164, 4/6/09	,,	62/3
,, ...	39	167, 4/6/09	,,	62/4

All the samples were collected by E. J. H. Webb.

Limestone-analyses quoted in N.Z. Geol. Surv. Bull. No. 17, p. 128.

Locality.	Collector's Number and Approximate Date.	Dominion Laboratory Report and Page.	Laboratory Number.
Fletcher Brook, towards head	19, 9/2/11	45th, 1912, p. 20	B 415/1
St. Andrew Stream, some distance above track-crossing	30, 18/3/11	,,	B 415/3
New Inland Road, towards north end of cliff	7 or 8, 1/2/11	,,	B 415/2
Lyell Bridge, Buller River	166, 3/5/13	47th, 1914, p. 21	D 711
Cape Foulwind Beach	123, 7/12/12	,,	D 9
Cape Foulwind Beach (grit)	124, 7/12/12	,,	D 10
Quarry, Cape Foulwind	108, 30/10/12	,,	D 6
Borehole (upper part), Cape Foulwind Quarry	129, 9/12/12	,,	D 16
Borehole (lower part), Cape Foulwind Quarry	130, 9/12/12	,,	D 17
South-east of quarry, Cape Foulwind (near Mr. John Fox's house)	128, 9/12/12	,,	D 13
Cape Foulwind (probably from quarry) ..	.. 1911	45th, 1912, p. 15	B 315/2

All the samples except the last were collected by P. G. Morgan. The exception was collected by Mr. H. R. Young, of Westport.

Cape Foulwind Lime-kiln.

During 1916 the Buller County Council built a lime-kiln at Cape Foulwind and began the production of lime. The kiln cost £523 16s., but if lined with firebrick set in fireclay would have cost about £625. The total capital expenditure, from a statement supplied by the Department of Agriculture, seems to have been £1,793 10s. 9d., of which £256 13s. 7d. represented "election expenses" (presumably cost of a poll of ratepayers), compensation, and procuration fees. The cost of producing lime during the three months July, August, and September, 1916, was 19s. 2d. per ton of lime produced. During August the detailed costs were—

	Per Ton. s.	d.
Quarrying and stripping	4	9
Knapping (breaking by hand)	4	9
Charging	2	10
Drawing	1	2
Fuel (coke, coal, and wood)	4	7
Horse	0	6
Royalty	0	9
	19	4

Cost of coal, 12s. 6d. per ton; cost of coke, 11s. per ton; cost of firewood (mill waste), 6s. per ton; average wages, 12s. per day; men employed, 5.

The estimated cost of production was 15s. per ton of lime, but in practice was found to be from 17s. to £1 per ton, not including interest on capital, depreciation, and probably other items. In considering the quarrying, breaking, and charging costs it should be remembered that at least 1¾ tons of rock and over ⅓ ton of fuel had to be handled for every ton of lime produced. The introduction of a rock-breaker would save approximately 3s. per ton of lime produced, and no doubt other improvements could be made which, though increasing the capital expenditure, would much reduce the cost of operation. The locality is one of the best in New Zealand for the production of cheap lime.

Summary of Limestone Resources.

Buller County is well supplied with limestone, but owing to its mountainous nature the transport and distribution of lime is a difficult matter. The agricultural portions of the Karamea and Little Wanganui districts are not far from poor limestone areas, but the high-grade band fit for calcination described by Webb outcrops well inland, and at points somewhat difficult or awkward of access. The same statement seems to be true of most of the low-grade limestone also. This is covered by gravels in many parts of the coastal belt. There is a moderately good band of limestone at Little Wanganui Head, but this is only 15 in. thick. From here south-westward there is plenty of low-grade argillaceous limestone along the coast-line.

The settlers on the New Inland Road near Corbyvale are fairly well situated for obtaining low-grade limestone, fit, however, only for pulverization, and not for calcination. The high-grade band crosses the New Inland Road close to the point where the old road or track diverges towards Rough-and-tumble Creek valley, but the quality at this particular point is not sufficiently good to make calcination advisable.

The Little Wanganui and Karamea districts must apparently rely on pulverized low-grade limestone to supply their lime requirements. Some search in order to ascertain the best situations for a temporary portable pulverization plant or plants seems advisable. Ultimately, when the district becomes well roaded, some of the better limestone outcrops—for example, those eight or ten miles up the Little Wanganui Valley—will no doubt be accessible.

The Seddonville district can obtain lime or pulverized limestone from Fletcher Creek, but probably a large plant at Cape Foulwind will be able to supply the district more economically than a small local plant.

The Cape Foulwind limestone is well situated for supplying the agricultural and the poor pakihi lands of the Westport district from Seddonville southwards. It can be cheaply worked, and is connected by rail with Westport, and therefore, of course, with Birchfield, Seddonville, &c. There seems to be no reason why cement-works also should not be established here.

The Charleston district and all the country southward has inexhaustible supplies of limestone of fair to good quality. Local calcining or pulverization plants may therefore be established where needed. If the Cape Foulwind Railway is extended to Charleston as proposed, then it would probably be better to obtain lime from a central plant at Cape Foulwind than to make it locally.

The eastern part of the Buller Gorge has abundant supplies of argillaceous limestone close to a good road, and there is limestone in many out-of-the-way places which will in some cases be found valuable for local use.

Means of Transport.

The entrance to the Buller River at Westport has been improved, so that now fairly large vessels can enter. Small steamers can enter the Mokihinui, Karamea, and Little Wanganui rivers, and Constant Bay, Charleston. Still smaller vessels occasionally enter the mouths of the Nile and Fox rivers. A railway runs from Westport to Mokihinui Mine, and sends off a short branch at Waimangaroa to Conn's Creek at the foot of the Denniston Incline, up and down which railway-trucks pass. From Westport a railway has been constructed to the entrance to the Lower Buller Gorge, and will ultimately be made through the gorge to Inangahua Junction. The Westport Harbour Board has made a railway to Cape Foulwind and Tauranga Bay for the transport of stone to Westport for harbour-works. This railway is connected with the other railways mentioned.

Buller County is at present roaded in a very simple manner. A main road has been made from Karamea to the Mokihinui River below Seddonville, where it joins the Seddonville–Westport Road. This continues as a vehicular road south to Addison's, Charleston, and almost to Brighton. Short branch roads lead to Millerton, Denniston, Cape Foulwind, &c. A well-made road leads through the Buller Gorge from Westport to Inangahua Junction, where it joins the Reefton–Nelson coach-road. A loop-line road on the south side of the Buller from Westport to the Lower Buller Ferry practically completes the list of roads. In addition there are various horse-tracks, some of which will in time be widened to or replaced by roads. Internal communications between the settled parts of Buller County are already fairly good, and no real difficulty need be experienced in the distribution of lime and pulverized limestone to the areas where they are needed.

Literature, &c.

As already stated, a large part of Buller County has been geologically surveyed in detail, and three bulletins have been published, two of which deal wholly with areas in the county, and one with an area partly in Buller, partly in Inangahua, and partly in Grey County. These bulletins are—

> N.Z. Geol. Surv. Bull. No. 11, 1910, "The Geology of the Mount Radiant Subdivision, Westport Division," by E. J. H. Webb; N.Z. Geol. Surv. Bull. No. 17, 1915, "The Geology and Mineral Resources of the Buller–Mokihinui Subdivision, Westport Division," by P. G. Morgan and J. A. Bartrum; and N.Z. Geol. Surv. Bull. No. 18, 1917, "The Geology and Mineral Resources of the Reefton Subdivision, Westport and North Westland Divisions," by J. Henderson.

The lists of literature contained in these bulletins include practically all the publications having any bearing on the geology of Buller County, with the exception of a few that are of little importance, one or two that refer to the extreme north and north-east of the county (Mount Domett, Mount Cobb, Mount Peel, and Mount Arthur districts), and those published since the bulletins were issued. In the last two classes are—

> Rep. Geol. Explor., No. 4, 1867, pp. 27–28, 31–32; No. 12, 1879, part of pp. 121–31 and map opposite p. 122 (Mount Arthur, Mount Peel, &c.).
>
> Trans. N.Z. Inst., vol. 49, 1917, pp. 419–20 (granodiorite with primary epidote, Reefton).

A few omissions from the list of literature in Bulletin No. 17 are made good by the list in Bulletin No. 18.

7. MURCHISON COUNTY.

Murchison County is a mountainous district lying in the heart of the old provincial district of Nelson. Its geology is much the same as that of the adjoining parts of Buller and Waimea counties. Palæozoic schists, greywackes, argillites, and marbles, together with great intrusions of granite, form the mass of the mountain-ranges. Some old Mesozoic argillites and greywackes may be present in the Spenser and St. Arnaud mountains. Old and Middle Tertiary conglomerates, sandstones, shales, limestones, claystones, &c., occur in patches, either as remnants on the highlands, as fault-involved bands, or as down-faulted and down-warped masses in the valleys. Coal-seams appear in many places, but the areas of workable coal are small. The valleys, if not gorges or cañons, have their floors covered with Pleistocene and Recent fluviatile gravels, and are bordered by terraces of the same material. In places morainic gravels appear. The arable land of Murchison County is confined to the broader parts of the river-valleys, and is found chiefly near Murchison and in the Maruia Valley. The county therefore, as a whole, does not require a great deal of lime, and at the present time the neighbourhood of Murchison is the only locality where it is greatly needed. The localities where limestone occurs are indicated in the following paragraphs.

Ordovician crystalline limestone or marble extends from the Upper Wangapeka district into Murchison County, where it covers a small area near the head of the Owen. Marble, probably of the same age, and certainly not younger than the Silurian, occurs in the southern portion of the county, where it forms a belt half a mile in width and several miles in length, stretching from the upper valley of the Maruia into that of the Grey River. The same rock also forms an isolated hill in the Maruia Plains opposite the Alfred River, and is continued in the hill that lies between the Alfred and the Sheriff rivers (Cox, 1884 report, p. 3). No analyses of these marbles are available, but they appear to contain a high percentage of calcium carbonate, and are without doubt potential sources of lime.

Dr. J. Henderson visited the Murchison district in October, 1916, and supplied the following special report, which covers practically all that is known concerning the Tertiary limestones of the county:—

" Murchison is situated at the junction of the Buller and Matakitaki rivers, near the centre of an irregular area of river-flats and terraces containing in all about six square miles of arable land. The hills rising to the west of the Matakitaki are carved from a belt of steeply dipping calcareous beds, which again appear on the north side of the plain along the right flank of the Matiri River. The lime-bearing beds are not of uniform quality, and all contain a considerable admixture of clay or sand. The best occurs on Mr. C. O'Brien's land, close to the main road and about two miles from Murchison. This layer is 15 ft. to 20 ft. thick, and consists of a hard non-porous limestone of brownish colour, which on analysis was found to contain 78·21 per cent. of calcium carbonate and 18·78 per cent. of matter insoluble in acid. The upper 8 ft. of this layer, which resists the weather rather better than the lower portion, contains 77·00 per cent. of calcium carbonate and 19·12 per cent. of insoluble matter. On the north side of the Buller, on the road between Fern Flat and the Matiri, the same belt is exposed, but here the layer of best appearance yielded only 59·36 per cent. of $CaCO_3$, with 34·20 per cent. of insoluble matter. The sample was taken from an exposure about a chain in length occurring beside the road between All Nations Point and the Matiri Bridge, and about 30 chains from the latter. A little nearer the bridge a small stream descending from the steep limestone hills has formed an inconsiderable deposit of travertine or calcareous sinter.

" In the gorge of the Buller, about two miles above Newton Flat, limestone involved in a powerful fault outcrops at several points for a distance of 30 chains along the road. A few chains down the road from Brown Creek high-grade limestone forms a bluff, while 20 chains up the road from Brown Creek a similar limestone containing many quartz-grains is to be seen. A sample from the first-mentioned outcrop is said to have yielded over 97 per cent. of $CaCO_3$, while a sample taken by the writer from the second gave 83·21 per cent. of $CaCO_3$ and 15·48 per cent. of insoluble material. Stone corresponding to the first-mentioned sample would make first-class agricultural lime, but material resembling the second sample is more suitable for pulverization than calcination.

" In addition to the localities mentioned, flat-lying limestone forms a high-level plateau in the fork of the Buller and Maruia rivers. This area, the northern corner of which is known as the Sphinx Rock, covers about a square mile. The limestone is thick, but impure, and the best samples are reported to have yielded only about

60 per cent. of calcium carbonate. This, combined with the obvious difficulty that would be experienced in working it, places this deposit out of the question as a source of agricultural lime at the present time. Southward the hills between the Maruia and Matakitaki rivers are capped by gently dipping limestone, which rises high on the flanks of Mount Mantell.

"The deposit on O'Brien's land is centrally placed in respect to the arable land of the district. It is too impure for calcination or for 'burning,' and if used for agricultural purposes must be ground. Its situation on a steep hillside is an important factor in cheap working, since transport from the quarry to the rock-breaker and the other pulverizing-machinery can be accomplished by gravity alone. For the reasons indicated, this locality is recommended as a site for a trial plant."

The only analyses available represent four samples of Tertiary limestone collected by Dr. J. Henderson in 1916. They are the following:—

	(1) Per Cent.	(2) Per Cent.	(3) Per Cent.	(4) Per Cent
Matter insoluble in acid	15·48	18·78	19·12	34·20
Lime (CaO)	46·60	43·80	43·12	33·24
Moisture and organic matter	0·11	0·27	0·21	1·08
Calcium carbonate ($CaCO_3$)	83·21	78·21	77·00	59·36

References.—(1) Two miles east of Newton Flat, Lyell Survey District. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Original Lab. No. 1588; published No. 1578/11.

(2) Layer, 20 ft. thick, C. O'Brien's land, two miles from Murchison. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Original Lab. No. 1586; published No. 1578/9.

(3) Upper 8 ft. of No. 2. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Original Lab. No. 1587; published No. 1578/10.

(4) Thirty chains from Matiri Bridge on road to Fern Flat. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Original Lab. No. 1585; published No. 1578/8.

In the upper Maruia Valley there are some remarkable calcareous sinter or travertine terraces just below the junction of the right- and left-hand branches of the Alfred River. Cox states that these terraces are about 400 ft. high in the aggregate, and have been formed by calcareous water flowing over a form of moss (? alga) which grows luxuriantly on the calcareous deposits. In the course of time layer upon layer is petrified, and a fresh growth continually forms on the top. The general effect is very beautiful (1884 report, p. 3). With Cox's description compare Bell, Clarke, and Marshall's description of the similar deposit in the Miner Valley, Dun Mountain district (N.Z. Geol. Surv. Bull. No. 12, p. 28, and this bulletin, pp. 179–80).

Summary of Limestone Resources.

Murchison County, unlike its neighbours Buller and Waimea counties, has small limestone resources, but as the amount of arable land is small it can cut its coat according to its cloth. The limestones near Murchison are, on the whole, too poor to be calcined, but will be satisfactory if used after pulverization as a soil-dressing, and the quantity, though not large, will supply the needs of the district for many years to come. The marble at the head of the Maruia Valley can be utilized as a source of lime for the Maruia Plains.

Means of Transport.

No railway enters Murchison County, but Glenhope, the terminus of the railway from Nelson, is only a mile or two outside the county. When the railway is extended to Murchison the lands near the line, and Murchison district generally, will be able to obtain lime from Kaka or some other part of Waimea County, or possibly from the

Owen district. The railway north from Reefton ends at Inangahua Junction, not a great many miles from Murchison County boundary; but though an extension of this line through the Lyell Gorge is proposed, there seems little justification for the construction of so expensive a work, and one may doubt if it will ever be made. A railway eastward from Reefton up the Inangahua Valley, then over a saddle into the head of the Maruia, and thence through the Cannibal Gorge into Canterbury, was proposed many years ago,* and may perhaps be made some day. A branch line down the Maruia and Matakitaki valleys to Murchison is feasible.

The roads of Murchison County are few. They consist mainly of that part of the Reefton–Nelson coach-road which is between Lyell and Hope Saddle, of a road from Murchison up the Matakitaki Valley and thence into the Maruia Valley, and of an old road, not much used, leading through the Upper Buller Valley to the Wairau Valley, Marlborough.

Literature.

The principal references to the geology of Murchison County are—

Haast, Julius von: "Report of a Topographical and Geological Exploration of the Western Districts of the Nelson Province, N.Z.," 1861, pp. 2–25, 71–75, 89–103, 121–22, 125, 127, 130, &c.

Rep. of Geol. Explor., No. 9, 1877, pp. 40–41; No. 16, 1884, pp. xv–xviii, 1–10; No. 18, 1887, pp. xliii–xliv; No. 19, 1888, pp. xx–xxv, xxxix–xl, 74–88.

Parl. Paper C.–13, 1895 (bound in Mines Rep.), part of pp. 1–28. Parl. Paper C.–9, 1896 (bound in Mines Rep.), part of pp. 1–28.

Trans. N.Z. Inst., vol. 43, 1911, part of pp. 297–315.

9th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1915, pp. 102–3.

8. AMURI COUNTY.

The rocks of Amuri County belong to two great groups of strata. The first, of old Mesozoic age, consists mainly of greywackes and argillites. It forms the eastern slopes of the Southern Alps, the Spenser and St. Arnaud ranges, and the main part of the Seaward Kaikoura Mountains, a portion of which is in Amuri County. The old rocks, in fact, form practically the whole of the western and northern parts of the county, and appear as isolated ranges in the southern and eastern parts. The second group consists mainly of Tertiary strata (calcareous claystone, sandstone, limestone, &c.) developed round the margins of the great Hurunui–Waiau basin (a depression formed by earth-movements), and no doubt is present beneath the gravels that form the floor of the basin. Probable Cretaceous rocks are developed to a small extent among the Mendip Hills, along the right bank of the Conway River, and perhaps elsewhere. Volcanic rocks of Tertiary age appear at various points between the Waiau Plain and the Conway River. In places they are associated with a limestone horizon. The Hanmer Plain forms part of a tectonic depression similar to the Hurunui–Waiau basin, but smaller. There is no evidence that either basin has ever been a lake.

No limestone is known to occur in the old Mesozoic rocks of the county, and therefore search is limited to the areas where Cretaceous and Tertiary rocks outcrop.

So far as known, limestone deposits occur only in the eastern part of the county, chiefly along the western margin of the Hurunui–Waiau basin. Here their principal development is in the valley of Mason River and its branch, Lottery Creek, where, according to McKay (Rep. of Geol. Explor., No. 17, 1886, p. 106), a thickness of from

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* Rep. Geol. Explor. No. 16, pp. 4, 8, and map opposite p. 2.

50 ft. to 70 ft. of limestone is exposed near Sherwood Station. This he illustrates by the subjoined section (fig. 6):—

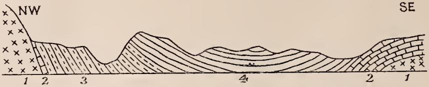

Fig. 6.—Section on Lottery Creek near Sherwood Station.

1. Volcanic rocks and tufas of Dog Hills and limestone gorge of Lottery Creek. 2. Limestone forming a thin band at the western end of the section, but on the eastern side 50 ft. to 70 ft. thick, which, with the underlying tufas, is cut through to form the limestone gorge of Lottery Creek. 3. Green and grey concretionary sandstones of Awamoa Series. 4. Soft grey sands of Pareora Series.

A thick band of limestone crosses the Mason River at the narrow gorge known as "The Gates." Limestone crowns the range on the east side of the valley below "The Gates," but McKay thinks this is not the same limestone as that seen in the gorge of the Lottery below Sherwood Station. Near the junction of the Lottery and Mason rivers bands of sandy and subcrystalline limestone appear, but are poorly developed. Beds of limestone (shelly, tufaceous, or subcrystalline) are exposed on Red Spur, south-east of Highfield Ridge, and not far from the Stanton River. Farther south limestone occurs at Isolated Hill, near Culverden, whence it extends to the southern bank of the Waiau River, and also near Balmoral (west of the railway-station of that name) and Hurunui Mound. The limestone at Marble Point, in the gorge of the Waiau between Culverden and Hanmer, also deserves mention. All the limestones mentioned are of Middle Tertiary age. As McKay supposes, there are probably two limestone horizons. The limestone of the lower horizon is subcrystalline or close-grained; that of the upper horizon is rubbly, and resembles the Mount Brown limestone of Waipara County. The other Tertiary rocks of Amuri County are in many places calcareous, and contain numerous concretions, &c..

No analyses of calcareous rock from Amuri County are available.

Summary of Limestone Resources and of Means of Transport.

Not much is known about the limestone resources of Amuri County. They appear to be small, but further exploration may lead to a revision or qualification of this statement. There is some limestone on the borders of the principal agricultural district, the Hurunui-Waiau Plain, and this may be found to supply the needs of that district fairly well. Analyses of representative samples are badly needed. Limestone or lime may be imported from Waipara County by means of the railway, which now reaches Waiau. The settled part of Amuri County is well roaded, but the county contains a large area of high mountainous country intersected by narrow river-valleys, in places widening to flats, which is given over to sheep-farming, and is hardly roaded at all.

Literature.

The following are the principal references to the geology and structure of Amuri County:—

Quart. Jour. Geol. Soc., vol. 22, 1866, part of pp. 254–60 (W. T. L. Travers).

Rep. of Geol. Explor., No. 4, 1868, pp. 38–41; No. 6, 1871, pp. 25–46; No. 8, 1877, pp. 27–58; No. 9, 1877, p. 39; No. 13, 1881, pp. 83–107; No. 17, 1886, pp. xiii–xxxvii, 27–136; No. 20, 1890, pp. xxi–liv, 1–16, 85–185; No. 21, 1892, part of pp. 1–28, 146.

Haast, Julius von: "The Geology of Canterbury and Westland," 1879. The northern part of the geological map with this publication illustrates the geology of an area adjoining Amuri County.

Trans. N.Z. Inst., vol. 6, 1874, part of pp. 297–309 (Travers); vol. 47, 1915, pp. 347, 348.

9. AWATERE COUNTY.

Awatere County practically consists of the Awatere Valley and the northern half of the Clarence Valley. The geology of this county and the adjoining Kaikoura County is most interesting and important.

The mountain-ranges of the county are formed mainly of a series of greywackes, argillites, and allied rocks, probably mainly of old Mesozoic age, but portions may be of Carboniferous or rather Permo-Carboniferous age. Much younger than these rocks is a series of conglomerates, sandstones, mudstones, and limestones, all probably of Cretaceous age. In many places igneous rocks intrude both sets of sedimentary strata. Another set of conglomerates, calcareous claystones, and sandstones is well developed in the lower Awatere Valley and thence southward to the Ward district. This is of Miocene age. A remarkable conglomerate, supposed by McKay to be of Pliocene age (probably a correct conclusion), is found as a long fault-involved band on the north-west side of the Clarence Valley. Similar but shorter bands or lenses are found south-east of Lake Grassmere, in the valleys of Kekerangu and Shades streams, and elsewhere. The high gravel terraces on both sides of the mouth of the Clarence River are believed to be of post-Pliocene age. Recent gravels and sands cover the river-flats of the upper and lower Awatere Valley, the Flaxbourne River, &c. Along the coast in places are raised beaches, sandhills, &c.

The old rocks of the lower Awatere Valley, and probably elsewhere, contain bands of calcareous argillites or shales, diabasic tuffs (apparently similar to those of the Wellington district), and in one place at least limestone. This locality is on the Blenheim side of Taylor's Pass (by which the main road from Blenheim reaches the Awatere Valley). McKay describes the rock as interbedded with red and green argillites, diabasic tuffs, &c., and doubtfully correlates it with the Maitai limestone of the Nelson district (1890 report, pp. 119, 120, 139). He states that the limestone contains fragments of a shell (? *Aphanaia*) similar to that found in the Maitai limestone; and if this is so it follows that his tentative correlation is probably correct. It is not likely that the Taylor's Pass limestone will be of great value as a source of lime, but tolerably good samples appear to have been obtained from it. Moreover, the fact of its occurrence points to the probable presence of similar bands of limestone in other parts of Marlborough and Awatere counties.

The following analyses of limestone from Taylor's Pass are available:—

	(1) Per Cent.	(2) Per Cent.
Lime (CaO)	50·90	51·18
Carbonic anhydride (CO_2)	40·00	40·21
Moisture and organic matter	0·30	0·50
Calcium carbonate (by addition of CaO and CO_2)	90·90	91·39
Quicklime (CaO) in calcined stone (Aston)	80	80

Reference.—Forwarded by Cottrell and Kennedy. Dom. Lab. 42nd Ann. Rep., 1909, p. 21. Lab. Nos. 2119/1, 2. Calcium carbonate in No. 2 given as 91·40 per cent., presumably by including figures in third place of decimals.

The Cretaceous rocks of Awatere County are more or less calcareous and concretionary throughout. The uppermost member of the series is a thick limestone of great importance, known to geologists as the Amuri limestone, the place-name being derived from Amuri Bluff, in Kaikoura County, and not from Amuri County, where this limestone occurs only in small amount. Though the weight of evidence indicates a Cretaceous age for the whole of the Amuri limestone, there is also evidence supporting an Early Tertiary age for the upper part at least. It is therefore quite proper to suspend judgment on this point, and the use of the name "Amuri limestone" affords a way out of the difficulty. The Amuri limestone is widely developed from the Cape Campbell district to the Waipara River in North Canterbury, and is found also in the Trelissick Basin, west of the Mount Torlesse Range, central Canterbury. A similar limestone is found in some parts of the North Island (see p. 92).

The Amuri limestone is generally a hard close-grained rock, almost unfossiliferous except for the remains of Foraminifera. Some outcrops are chalky. In many places it contains flints, and there are localities where hundreds of feet of the limestone have been altered to flint. In general the Amuri limestone is a somewhat siliceous rock, not sufficiently pure to be well adapted for calcination.

A belt of Amuri limestone is practically continuous from Cape Campbell to the Clarence River, where it passes out of the county. In places there are two or even more bands, the repetition being due to faulting and other earth-movements. Amuri limestone has a great development on Benmore, south-west of Ward, and in the upper valley of the Ure River, whence it extends in a continuous fault-involved belt along the western side of the valley of the Upper Clarence for more than thirty miles. An eastern offshoot or leg continues down the coast-line. A similar but narrower belt of Amuri limestone and associated rocks is to be found in the valley of the Awatere River from the Jordan to the Tone River, a distance of twenty miles.

Throughout Awatere County the limestone layers are much disturbed or broken, and large portions of them have been involved in great earth fractures or faults. In consequence the limestone has a somewhat erratic distribution. In places the earth-movements have produced wide zones of crushed and broken rock. This has an important bearing on the economic value of the deposits; for the bulk of the limestone crushed by faults is soft and friable, and is suitable for spreading on land without preliminary treatment other than separating the lumps by sieving. Even where the limestone is not completely crushed the earth-movements have broken it into innumerable flakes, producing a considerable amount of fine material in the process. Faulted and shattered rocks are peculiarly liable to break down under atmospheric weathering, and in hilly country each rill and creek at its outlet from the hills forms a shingle-fan which contains a large proportion of fine material. In the case of limestone débris, weathering tends to break down the larger lumps and to render the fragments more or less friable.

In the Cape Campbell and Ward districts there is much friable limestone as well as great quantities of the hard Amuri limestone. The limestone stratum is several hundred feet thick, but no measurements of its exact thickness have been made. The dips of the various belts are steep, and either to the north of west or to the south of east, the strike being therefore to the east of north, nearly in accordance with the general structure of the old Marlborough Provincial District. The Cape Campbell and Ward districts were visited by P. G. Morgan in December, 1915, and his report of 1916 is embodied in the following paragraphs.

A belt of Amuri limestone extends southward from a point on the coast-line between Lake Grassmere and Clifford Bay, and as viewed from the western side of Fisherman Creek valley appears to run out to sea several miles to the south. This belt is fault-involved, and in places has been so crushed that the naturally hard rock is reduced to a soft white chalky powder,* containing only a small proportion of hard lumps. Outcrops of this material may be distinguished from a distance by their general appearance, which is that of an irregularly shaped white sheet spread on the ground. Crags and pinnacles are absent, and the outcrop as a rule is peculiarly white. So far as can be seen, the quantity of crushed limestone in Fisherman Creek valley and elsewhere is very large, and the quality is fair. The facilities for mining are good, but this is hardly the case as regards transport, unless a large steady demand should arise, in which event the construction of a tram-line would be advisable.

The outcrops visited were approximately four miles from the railroad as the crow flies, and probably 400 ft. or 500 ft. above sea-level. The following analyses represent (1) a sample of hard limestone from the coast-line between Cape Campbell and Lake Grassmere, and (2) an air-dried sample of soft limestone from an outcrop on the western side of Fisherman Creek valley (east of Lake Grassmere) :—

	(1)	(2)
Matter insoluble in acid	17·03	27·43
Alumina and iron oxide	1·19	1·64
Lime (CaO)	44·12	36·92
Magnesia (MgO)	0·16	0·22
Carbonic anhydride (CO_2)	33·28	27·60
Moisture and organic matter	3·93	6·06
Phosphoric anhydride	0·13	0·14
	99·84	100·01
Calcium carbonate ($CaCO_3$), per cent.	75·2	62·2

References.—10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, p. 15 ; and Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. Nos. G 37 and G 38. Samples collected by P. G. Morgan, December, 1916.

Mr. B. C. Aston, Chief Chemist, Agricultural Department, who visited the Cape Campbell district shortly after Mr. Morgan, obtained a sample of soft limestone from the spot known locally as the "Giant's Shirt," situated on Mr. Cumming Law's property adjoining Teschemaker's. He has kindly communicated the analysis, which shows 20·37 per cent. of insoluble matter, 2·37 of alumina and iron oxides, 73·68 of carbonate of lime, 2·10 of moisture, 1·48 of magnesia and undetermined, and traces of phosphoric acid : total, 100·00. Analyst's No. and date, G 688, 1916.

In 1913 Mr. S. W. Bowron sent a sample of limestone from the Cape Campbell district to the Dominion Laboratory. This contained 84·00 per cent. of calcium carbonate. (Dom. Lab. 47th Ann. Rep., 1914, p. 21. Lab. No. D 1058.)

In the hills between Ward and the sea-coast hard Amuri limestone is very prominent, especially on the property of Mr. A. Thomson, known as "Chancet." During 1915 the owner and Mr. A. McTaggart, of the Agricultural Department, discovered several deposits of soft limestone not far from Mr. Thomson's house. The locality is on the north side of the Flaxbourne River, near the road, and less than two miles from Ward Railway-station. A brief examination made by P. G. Morgan led to the belief that the deposits represent a band or bands of fault-crushed limestone, together with resulting slope deposits. They may, however, in reality consist of slope débris detached from the solid limestone outcrops by erosional agencies, and reduced to a powdery condition by weathering. The material at an outcrop on the hillside a short distance above the road east of Mr. Thomson's was light-pinkish to light-grey and white in colour. It crumbled easily between the fingers, and was mixed with a moderate proportion of hard pieces of limestone, mostly of small size. The moisture content of the deposit was considerable, and this statement applies to all soft or friable limestone accumulations exposed to moist climatic conditions. The sample taken, after being air-dried, contained: Matter insoluble in acid, 36·33 per cent.; alumina and iron oxide, 2·77 per cent.; lime (CaO), 32·13 per cent.; magnesia (MgO), 0·35 per cent.; carbonic anhydride (CO_2), 23·82 per cent.; moisture and organic matter, 4·57 per cent.; and phosphoric anhydride, 0·11 per cent.: total, 100·08. (Dom. Lab. 50th Ann. Rep., 1917, p. 20. Lab. No. G 39.) The carbonate of lime indicated by the analysis is 53·3 per cent. The lime present, however, is equivalent to 57·4 per cent. of calcium carbonate.

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* Weathering, as stated previously, assists in producing this result.

Mr. B. C. Aston has also examined the limestone deposits near Ward, and has communicated to the writers the results of analyses of numerous samples taken by himself and Mr. Thomson. These are set out in the following tables:—

I. Samples taken by Mr. Alex. Thomson, "Chancet," Ward.

	E 398/1.	E 398/2.	G 626	G 627.	G 628.	G 629.	G 630.	G 658.	G 659.
Insoluble matter (sand, &c.)	37·26	28·25	15·2	27·6	5·3	8·1	6·5	27·1	25·6
Iron oxide and alumina ..	1·26	1·28	1·3	1·7	1·6	2·0	1·4	3·8	3·7
Carbonate of lime ($CaCO_3$)	60·39	69·06	82·8	68·9	92·5	89·0	91·6	67·7	69·6
Magnesia and undetermined	1·09	1·41	0·7	1·8	0·6	0·9	0·5	1·4	1·1
	100·00	100·00	100·0	100·0	100·0	100·0	100·0	100·0	100·0

References.—E 398/1, hard limestone; E 398/2, ground limestone. (See also Dom. Lab. 48th Ann. Rep., 1915, p. 20.)

G 626–29, hard fine-grained stones; G 630, calcareous sinter (travertine); G 658 and 659, very soft samples.

II. Samples taken by Mr. B. C. Aston on or near the Property of Mr. Alex. Thomson ("Chancet").

	G 680.	G 681.	G 683.	G 684.	G 685.	G 687.
Insoluble matter (sand, &c.) ..	28·50	27·13	41·35	28·38	18·77	19·32
Alumina and iron oxides ..	3·93	2·46	6·38	3·11	1·98	1·67
Carbonate of lime ($CaCO_3$) ..	61·97	67·77	45·82	63·24	76·42	77·95
Moisture	2·89	Trace	4·63	2·81	1·75	Trace
Magnesia and undetermined ..	2·71	2·64	1·82	2·46	1·08	1·06
Phosphoric acid (P_2O_5) ..	Trace	Trace	Trace	Trace	Trace	Trace
	100·00	100·00	100·00	100·00	100·00	100·00

References.—G 680: From Mr. A. Thomson's, "Chancet," Ward. Taken from hole near plantation, 150 ft. above sea, 2 ft. to 3 ft. below surface.

G 681: At 400 ft. elevation. An outcrop of soft limestone mixed with hard lumps and some earthy matter.

G 683: At 500 ft. elevation, from another outcrop of soft stone.

G 684: At 600 ft., from very white deposit.

G 685: At 750 ft. Highest deposit of soft limestone.

G 687: Hard stone, taken from the "Chancet" Rocks (coastal), Ward.

These analyses were apparently made on well-dried samples. They show that the carbonate of lime in the soft limestone varies from 45·82 to 76·42 per cent., whilst the hard limestone contains from 60·39 to 92·5 per cent. of carbonate of lime. Thus there does not appear to have been any concentration of calcium carbonate in the soft limestone. The travertine, if correctly named, has been deposited from calcareous waters, and does not affect the question.

The writers understand that Mr. Thomson since 1916 has worked the soft-limestone deposits on his land, the material being sieved so as to separate the lumps, and that he has sold a considerable quantity of the sieved product to farmers in various parts of Marlborough. In 1918, however, the Commissioner of Crown Lands reported that owing to the supply of soft limestone workable without machinery having been practically exhausted, the works had been temporarily closed. (Report on Settlement of Crown Lands, Parl. Paper C.–1, 1918, p. 14.)

The amount of limestone in the Ure River district and in the Clarence watershed is enormous. Thus McKay, in describing the Clarence Valley, writes: "A remarkable feature in this part of the Inland Kaikoura chain is the flanking range of limestone hills which stretches from the source of the Ure River along the north-west side of the Middle Clarence Valley to the Bluff River, a distance of thirty miles, where, crossing to the south-east side of the valley, the limestones and associated rocks are continued for several miles to the south-west" (1886 report, p. 30). The limestone is well exposed in the gorges of the Ure River, and of the Swale, Mead, Dee, Branch, Dart, Muzzle, Bluff, and other streams that enter the Clarence from the Inland Kaikoura Mountains. In 1886 McKay estimated the thickness of the Amuri limestone in the Chalk Range, at Coverham, Clarence Valley, at not less than 1,500 ft., but he expressly stated that he included with this some younger rocks. This thickness is maintained for many miles to the south-west. In the Dart Gorge the thickness is 1,200 ft., and is not less in the Muzzle Gorge, though here the characteristic Amuri limestone has begun to lessen in thickness. As seen nearly ten miles farther south-west in the valley of Seymour River (Kaikoura County) the thickness is "inconsiderable" (1886 report, pp. 78, 79). A few years later McKay estimated the thickness of the Amuri limestone at Benmore and Coverham as not less than 1,000 ft., whilst to the south-west it lessens (1890 report, p. 162). The latest estimates of thickness has been made by J. A. Thomson, who considers that at Coverham the Amuri limestone and the flint-beds replacing limestone have a total thickness of 2,500 ft. (quoted by H. Woods in N.Z. Geol. Surv. Pal. Bull. No. 4, 1917, p. 2). In the Mead Gorge Thomson found 1,340 ft. of limestone underlain by 1,410 ft. of flint-beds with limestone intercalations (1916 paper, p. 53). Until exact measurements have been made, and the possibility of repetition through faulting eliminated, McKay's estimate of 1,000 ft. (apparently exclusive of the flint-beds, which he estimates as from 500 ft. to 1,000 ft. thick), being the more conservative, seems to be that most advisable to accept. Such a thickness leaves no room for complaint regarding the quantity of limestone in the Ure and Clarence valleys, but means of access are poor, and the stone in most localities is somewhat lacking as regards quality.

The following analyses may or may not refer to samples of Amuri limestone from the Ure River and the Inland Kaikoura Mountains.* The information given with them, however, does not define the localities with precision.

	(1)	(2)	(3)	(4)
Carbonate of lime	69·9	89·9	91·17	79·8
Carbonate of magnesia	1·5	1·7	2·62	0·6
Iron oxides and alumina	2·2	0·6	Traces	3·8
Matter insoluble in acid	26·4	7·8	6·21	11·4
Organic matter and water	..	..	..	1·9
Excess of lime (CaO) over that required to form carbonate	..	..	..	2·5
	100·0	100·0	100·00	100·0

References.—(1) (2) From Kaikoura Mountains (or Waikorai—see p. 27 of Lab. Rep.), forwarded by Mr. Jas. Davidson. Col. Mus. and Lab. 11th Ann Rep., 1876, pp. 17, 27. Lab. Nos. 1801/1, 2. No. 1 was a compact close-grained homogeneous stone of a pale-buff colour. It contained a considerable quantity of clay. No. 2 was similar but much paler in colour.

(3.) From Kaikoura Mountains, collected by Mr. Alex. McKay. Col. Mus. and Lab. 12th Ann. Rep., pp. 24–25, 52. Lab. No. presumably 1831 (p. 52). From same formation as Nos. 1 and 2 above.

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* Reference may also be made to analysis No. 5, p. 183 (arenaceous limestone from Parikawa or Parikawakawa).

(4) Marl or argillaceous limestone from near Ure River, forwarded by Mr. C. T. Hall Col. Lab. 40th Ann. Rep., 1907, p. 16. Lab. No. 449. The composition of the calcined stone is given. It would be suitable for the manufacture of cement if mixed with a small percentage of clay. "It might also be used for liming land in the district in which it is found."

The limestone of the upper Awatere Valley is thus described by McKay: "In the Awatere Valley the Amuri limestone is first met with on the north-west side of the river, a little below Glenlee old station, seven or eight miles below the junction of the Grey with the Awatere, and continues on that side of the river till not more than half a mile below the Grey junction; it then, for a short distance, is on both sides of the river, and finally crosses to the left bank a little above Gladstone Station. Higher up the valley it appears at several places between the Grey River and Castle Creek." (1890 report, pp. 162–63.) The Awatere Valley limestone is much thinner than that of the Clarence Valley.

The admittedly Tertiary rocks of Awatere County, though of a calcareous nature, are not known to include limestone. According to McKay calcareous sandstone overlies the Amuri limestone in portions of the Clarence Valley (1890 report, p. 163). J. A. Thomson states that in the Mead Gorge 150 ft. of hard argillaceous limestone (Weka Pass stone of McKay) overlies the rest of the limestone (1916 paper, p. 53).

The limestone of the upper Omaka Valley (Castle Hill, Pig Gully, &c.—see p. 182) may perhaps pass over the crest of the range into the watersheds of Black-birch and Blairich creeks. McKay mentions non-fossiliferous brown sands underlain by fossiliferous beds in the lower part of Black-birch Creek (1890 report, p. 167), but the upper valleys of this and Blairich Creek he maps as wholly composed of Carboniferous rocks.

McKay states that on the north-west side of the upper Awatere Valley great bodies of calcareous sinter or travertine have been formed in places favourable for their accumulation (1890 report, p. 117). The calcareous blue slates are the source of the travertine. Unfortunately, McKay does not give the exact situation of any of these deposits.

Summary of Limestone Resources, &c.

In the Amuri limestone Awatere County possesses an inexhaustible source of lime; but this limestone is usually somewhat impure, and therefore not well adapted for calcination, though undoubtedly this is a feasible operation for the better portions. Normally, the Amuri limestone is compact and hard, so that if it is to be pulverized it ought probably to be reduced to a fairly fine powder. Owing to its siliceous nature the Amuri limestone will quickly wear out some of the "lime-disintegrators" that are on the market, and are well enough suited for pulverizing less hard, purer limestones. It ought therefore to be reduced to powder by rock-breakers, followed by stamps, rolls, or well-made ball mills, such as are used for the pulverization of quartz. Fortunately, nature has provided large amounts of naturally comminuted limestone in the Ward and Cape Campbell districts. These are comparatively close to the railway, and can supply the needs both of Awatere and Marlborough counties for many years to come. Possibly the railway now being extended south along the coast will render accessible similar deposits between Ward and the Clarence River. The naturally comminuted or "soft" limestones are not of high quality, but can be very easily mined, and require no subsequent treatment except sieving and air-drying. As previously mentioned, they contain a good deal of moisture, except on the surface during dry weather.

Means of Transport.

As already mentioned, a railway traverses Awatere County from Marlborough County boundary to Wharanui, eight miles south of Ward and fifty-six miles from

Picton. It is to be continued to the Kaikoura district, and ultimately to North Canterbury. The coach and motor road from Blenheim traverses the county near the coast, and gives connection with Kaikoura and North Canterbury. There are various branch roads from this, the longest of which goes up the Awatere Valley, and is shown by maps as reaching its head and passing over a saddle into the Wairau Valley. The Clarence Valley (except towards its head) is as yet accessible by pack-track only. Awatere County has a coast-line, but no harbour worth mention. Clifford Bay, west of Cape Campbell, is fairly well sheltered from all except northerly weather, and there are various boat-landing places along the coast. The mouth of the Clarence can be entered by small vessels, and perhaps that of the Awatere also.

Literature.

The more important references to the geology and structure of Awatere County are contained in the following publications :—

Rep. of Geol. Explor., No. 4, 1869, part of pp. 34–40 ; No. 8, 1877, part of pp. 27–58 ; No. 9, 1877, pp. 185–91 ; No. 17, 1886, parts of pp. xiii–xxxvii, 27–136 ; No. 20, 1890, parts of pp. xxxvi–liv, 1–16, 85–185 ; No. 21, 1892, parts of pp. 1–28, 158–59 (Marlborough County).

6th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1912, part of pp. 7–9 ; 7th Ann. Rep., part of Parl. Paper C.–2, 1913, part of pp. 122–23 ; 9th Ann. Rep., part of Parl. Paper C.–2, 1915, pp. 100–1 ; 10th Ann. Rep., Parl. Paper C.–2B, 1916, pp. 15–19.

Trans. N.Z. Inst., vol. 37, 1905, pp. 547–48 (Park) ; vol. 45, 1913, pp. 308–15 (J. A. Thomson) ; vol. 48, 1916, pp. 48–58 (J. A. Thomson).

Cotton, C. A. : " The Physiography of the Middle Clarence Valley, New Zealand," *Geographical Journal,* vol. 42, 1913, pp. 225–46. Cotton, C. A. : " On the Relation of the Great Marlborough Conglomerate to the Underlying Formations in the Middle Clarence Valley, New Zealand," *Journal of Geology,* vol. 22, No. 4, May–June, 1914, pp. 346–63.

Woods, Henry : " The Cretaceous Faunas of the North-eastern Part of the South Island of New Zealand." N.Z. Geol. Surv. Pal. Bull. No. 4, 1917 (see especially pp. 1–12).

The most comprehensive reports dealing with the geology of Awatere and the neighbouring counties of Marlborough and Kaikoura are those of McKay, published in 1886 and 1890 (Rep. Geol. Explor., No. 17, pp. 27–136, and No. 20. pp. 85–185).

10. KAIKOURA COUNTY.

The geology of Kaikoura County is similar to that of Awatere, with the exception that Miocene rocks appear to be absent. The eastern leg of the broad area of Cretaceous rocks outcropping in the eastern part of Awatere County is continued southward into Kaikoura County, where it is exposed from the Clarence River along the valley of Puhipuhi Stream to the Hapuku Stream. South of the Hapuku the rocks of this age disappear beneath the gravels of the so-called Kaikoura Plain, but reappear in the valley of the Greenburn, the south branch of the Kahutara, and in that of the Charwell, or Cherwell (the more correct spelling—pronounced Charwell), a tributary of Conway River. Calcareous rocks occur extensively but irregularly throughout this zone, their mode of occurrence being similar to that of the same beds in Awatere County. In the upper Clarence Valley " Amuri " limestone appears on the Kaikoura County side of the main stream from Bluff River to Gore River, but not continuously. It is, moreover, thin in this part of the county. The same limestone occurs in various other localities in Kaikoura County—namely, Kaikoura Peninsula, Amuri Bluff (whence its name of "Amuri limestone"), in the basin of the Conway River north of Ferniehurst, and between Hundalee and the mouth of the Conway.

A limestone of undoubted Tertiary age occurs at Kaikoura Peninsula and Amuri Bluff, and probably also in the Clarence Valley, as mentioned under the heading of "Awatere County." This is not readily distinguished from the older Amuri limestone, on which, at both localities, it rests with apparent stratigraphical conformity. The younger rock is correlated with a similar limestone well developed at the Weka Pass in North Canterbury (see Waipara County), and is therefore termed the "Weka Pass stone." The maximum thickness of this rock on the Kaikoura Peninsula is about 120 ft. (Morgan, 1916, p. 21; also Speight and Wild, 1918, p. 83).

According to McKay (Rep. of Geol. Explor., No. 9, 1877, p. 176) limestone occurs in large quantity in the basin of the Puhipuhi River (north branch of the Hapuku River). The rock dips at a high angle, and the stream has formed a deep narrow gorge through it nearly a quarter of a mile in length. The same limestone again appears farther up the stream, but the beds at that point are of far less thickness than in the lower gorge.

The greater part of Kaikoura Peninsula is formed of hard compact limestone, the lower layers of which are very siliceous. The beds on the whole strike north-east. The dip is variable, and several faults traverse the area. A small plant has been erected at the eastern end of Kaikoura Township in order to pulverize limestone for agricultural purposes. On account of its accessibility by sea and its proximity to the fertile Kaikoura Plain, the Kaikoura limestone must be regarded as of great importance.

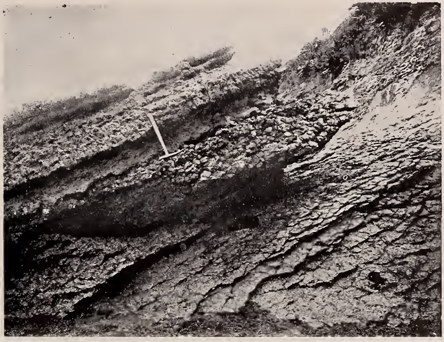
Analyses of Kaikoura limestone are as follow :—	(1)	(2)
Silica, &c.	12·68	(10·40)
Alumina and iron oxides	1·16	..
Lime	47·17	(49·38)
Magnesia	0·14	..
Carbon dioxide	37·00	(38·79)
Moisture and organic matter	1·85	1·43
	100·00	100·00
Calcium carbonate	84·00	88·17
Lime (CaO) in calcined stone (per cent)	77·10	82·6

References.—(1) From Kaikoura, forwarded by J. A. Johnston. Dom. Lab. 47th Ann. Rep., 1914, p. 21. Lab. No. 1220/2. Other samples forwarded at the same time by Mr. Johnston contained 58·07, 29·55, 41·70, and 47·20 per cent. of carbonate of lime. Lab. Nos. 1220/1, 3, 4, 5.

(2) From Kaikoura, forwarded by Mr. George Renner. Aston, B. C.: 12th Ann. Rep. Dept. Agric., Chemical Division, 1904, pp. 143, 151. Analyst's No. E 255.

The limestone near Amuri Bluff has been carefully examined by geologists on several occasions. It forms high cliffs north of Amuri Bluff proper, and portions appear to be of fairly high grade. Other layers are flinty or siliceous. McKay measured five sections in this locality, and found that the Amuri limestone varied in thickness from 260 ft. to 630 ft. (Rep. of Geol. Explor., No. 9, 1877, p. 183.)

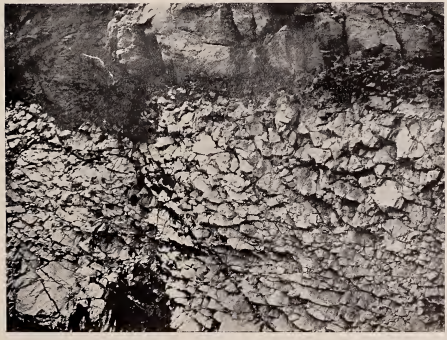
Many years ago the limestone north of Amuri Bluff was quarried and shipped to Christchurch, where it was used as a building-stone or burnt for quicklime. (Rep. of Geol. Explor., No. 4, 1869, p. 39.)



A. Nodular Layer in Amuri Limestone, South Side of Amuri Bluff, Kaikoura County.

The parallelism of the layers is very marked.

[*From a paper by R. Speight and L. J. Wild in vol. 50, Trans. N.Z. Inst.*]



B. Contact of Much-jointed Amuri Limestone with Overlying Greensand Layer containing Phosphatic Nodules, Port Robinson, Cheviot County.

A small fault is also apparent.

[*From a paper by R. Speight and L. J. Wild in vol. 50, Trans. N.Z. Inst.*]

The following analyses of limestone from Amuri Bluff have been made, but none of these can be considered representative :—

	(1)	(2)	(3)	(4)
Matter insoluble in acid	31·2	31·9	6·41	19·96
Silica soluble in acid	1·0	1·0	..	..
Alumina	6·5	6·4	6·59	3·24
Iron oxides			Traces	7·20
Moisture and organic matter ..	1·1	1·2	..	..
Calcium carbonate	68·6	54·9	84·84	66·36
Magnesium carbonate	1·7	1·5	2·16	3·24
	110·1	96·9	100·00	100·00

References.—(1) Septarian nodule or concretion forwarded by Dr. Julius von Haast. Col. Mus. and Lab. 6th Ann. Rep., 1871, pp. 28–29, 32. Lab. No. 1067/1. There is an error in the statement of the analysis. Probably matter insoluble in acid should be 21·2 per cent.

(2) Part of No. 1, freed from calcareous veins. Lab. No. 1067/2.

(3) Lithographic limestone from Amuri Bluff, collected by Mr. Alex. McKay (Geol. Surv.). Col. Mus. and Lab. 12th Ann. Rep., 1878, p. 26. Lab. No. 1927. A nearly homogeneous stone, very fine-grained, of light-cream colour. Subconchoidal fracture.

(4) Cone-in-cone limestone, Amuri Bluff, collected by Mr. Alex. McKay. Col. Mus. and Lab. 21st Ann. Rep., 1886, p. 37. Lab. No. 4274. The sample was of brown colour, moderately hard, and broke into pieces, most of which were of a conical shape.

Summary of Limestone Resources, &c.

Kaikoura County is well supplied with limestone, but some exploration and much careful sampling are required before definite opinions as to the quality of the limestone and the best points of attack can be given. For example, limestone at Kaikoura is being quarried at a very convenient point for transport; but there are several other localities on this small peninsula where the stone appears to be of better quality than at the present quarry, and transport, though at some expense, can be arranged. The limestone in the Amuri Bluff and Oaro River district, as at Kaikoura, needs to be sampled in order to ascertain the quality, thickness, and situation of the best layers.

An account of the phosphate occurrences of the county is given in Chapter V (Part II of this bulletin).

Means of Transport.

The bay on the north side of Kaikoura Peninsula is sheltered from all prevailing winds except the north-east. It contains some dangerous rocks. Small steamers can generally berth at the wharf at the eastern end of Kaikoura Township. There are boat-landing places at Waipapa, two or three miles south of the mouth of the Clarence, north of Amuri Bluff, and elsewhere.

Kaikoura County has no railway, but the railways to the north and south are to be continued till they meet. The chief road is that part of the Blenheim–Christchurch motor and coach road within the county. This road follows the coastline as far south as Oaro Stream (north of Amuri Bluff), where it goes a few miles inland. There is also an inland road from Kaikoura to Greenhills, and thence to Waiau. The Kaikoura Plain, the principal area of settlement, is well roaded, and a road goes a few miles up the Puhipuhi Valley, north of Kaikoura Township. No other roads of consequence as yet exist in the county.

Literature.

The following list contains the principal references to the geology of Kaikoura County :—

Rep. of Geol. Explor., No. 4, 1868, pp. 37–41 ; No. 6, 1871, pp. 25–46 ; No. 8, 1877, part of pp. 27–58 ; No. 9, 1877, pp. 172–84 ; No. 17, 1886, parts of pp. xiii–xxxvii, 27–136 ; No. 18, 1887, pp. ix–xiv, 74–78 ; No. 20, 1890, parts of pp. xxxvi–liv, 1–16, 85–185 ; No. 21, 1892, parts of pp. 1–28.

6th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1912, part of pp. 7–9. 7th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1913, pp. 130, 131. 10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, pp. 13–15, 19–25.

Trans. N.Z. Inst., vol. 43, 1911, pp. 389, 390, 523, 524 ; vol. 48, pp. 48–58 ; vol. 50, 1918, part of pp. 65–93 (R. Speight and L. J. Wild).

To above list add the papers by C. A. Cotton cited under " Awatere County," and N.Z. Geol. Surv. Pal. Bull. No. 4, 1917 (H. Woods), pp. 13–15 and most of pp. 17–37.

11. CHEVIOT COUNTY.

The geology of Cheviot County is similar to that of Kaikoura and Awatere counties, but old Mesozoic rocks are not so prominent, and the Amuri limestone is very poorly developed. Limestone of Tertiary age is to be found on the coast at Gore Bay and Port Robinson. Farther north, south of the Jed River, a bed of white and earthy-looking limestone 30 ft. thick is well exposed half a mile inland. It is underlain by calcareous claystone, which contains lenses up to 20 ft. thick of limestone and calcareous sandstone. Farther up the Jed, limestone probably belonging to the same horizon occurs for three miles along the south-western side of the valley. About a mile below Cheviot Township (Mackenzie) the calcareous beds cross the Jed and thence northward flank the western slopes of the Cheviot Hills, where limestone forms a prominent rocky ridge high on the northern spur of Mount Maccoinnich, a mile and a half east of Cheviot Township. Conglomerate with a calcareous matrix outcrops near the road between Gore Bay and the Hurunui flats, and also at several points near Cheviot Township, but these occurrences have no value as a source of agricultural lime.

The remains of an old kiln are to be seen near the road along the coast a little south of the mouth of Jed Stream. The limestone in this locality is of good quality, and, moreover, conveniently situated for working. It is at least 20 ft. thick, and over a small area could be obtained practically without stripping. The limestone bed is overlain by a thin band of pebbles of phosphatic limestone, and by a bed of soft calcareous sandstone several feet thick, also containing phosphatic pebbles. A deposit of " soft " or friable limestone is reported by Mr. A. McTaggart, of the Agricultural Department, to occur on the Cheviot Estate four miles from Domett Railway-station.*

The following analyses represent Cheviot County limestones :—

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid ..	4·16	53·76	21·48	21·37	9·06	10·40
Alumina and iron oxides ..	0·43	2·48	1·88	3·49	1·20	1·30
Moisture	1·12	4·18	..	..	..	..
Calcium carbonate ($CaCO_3$)	90·65	38·34	74·11	70·17	89·46	86·82
Magnesium carbonate ($MgCO_3$), &c.	3·64	1·24	2·53	4·97	0·28	1·48
	100·00	100·00	100·00	100·00	100·00	100·00

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* Jour. Agric., vol. 11, 1915, p. 394. The analysis of limestone (80·80 per cent. of calcium carbonate) given on p. 330 of the same volume probably represents a sample from this deposit.

References.—(1) Loose granular limestone, Cheviot Estate, forwarded by Lands and Survey Department. Col. Lab. 28th Ann. Rep., 1894, p. 13. Lab. No. 6376. The analyst remarks that the sample, from its structure and composition, appears to be chalk. "It is admirably adapted for burning into lime."

(2) Soft calcareous freestone from Cheviot, forwarded by the Department of Lands and Survey, Christchurch. Col. Lab. 32nd Ann. Rep., 1899, p. 6. Lab. No. 8127/1. "It is of fine grain, of a pleasant shade, and easily worked." Two similar stones were forwarded at the same time (p. 7 of report).

(3) (4) Cheviot, forwarded by J. Gibson. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. Nos. D 1107/1, 2.

(5) (6) Cheviot. No. 5 forwarded by New Zealand Farmers' Union, and No. 6 by Mr. G. W. Forbes. Dom. Lab. 48th Ann. Rep., 1915, p. 21. Lab. Nos. E 808 and 912.

The following determinations of calcium-carbonate content are given by B. C. Aston in the *Journal of Agriculture*, vol. 11, No. 4, October, 1915, page 330:—

		Per Cent.
G 218:	Soft limestone from Cheviot	88·92
G 219:	Soft limestone from Port Robinson	72·92
G 220:	Limestone from Port Robinson	60·68
G 221:	Very soft stone from Port Robinson	26·67
G 222:	Soft limestone from Domett	80·80

Summary of Limestone Resources, &c.

The limestone of Cheviot County has not been fully explored. There are several fairly large deposits, and probably the county is on the whole well supplied with limestone. Some of the deposits are well situated for supplying neighbouring agricultural areas, but the writers have not learnt of any large deposit that is close to the railway-line and at the same time can be easily worked. Further exploration and sampling of the known deposits by experienced persons are needed. This work could most advantageously be carried out in conjunction with a detailed geological survey, for the rock-structure of the county is highly complicated, and problems requiring geological knowledge for their solution are sure to arise.

Means of Transport.

A railway-line runs through the county as far as Parnassus, eighty-five miles from Christchurch. The trunk road of the county is the coach and motor road, which is close or fairly close to the railway-line, and continues north to Kaikoura. From it branch roads to Port Robinson and some of the inland districts have been made. The county possesses the very poor harbour of Port Robinson, and there are various boat-landing places along the coast.

Literature.

References to the geology of Cheviot County are to be found in the following reports:—

Rep. of Geol. Explor., No. 4, 1869, pp. 38–41; No. 6, 1871, part of pp. 25–46; No. 8, 1877, part of pp. 27–58; No. 15, 1883, p. 79; No. 20, 1890, part of pp. 85–185.

McKay, Alex.: "Report on the Recent Seismic Disturbances within Cheviot County . . . ," 1902.

Henderson, J.: "Notes on the Geology of the Cheviot District." N.Z. Jour. Sci. and Tech., vol. 1, No. 3, May, 1918, pp. 171–74.

12. INANGAHUA COUNTY.

Inangahua County is a compact inland area containing a central north and south valley, with mountains to the east and the west.

The oldest rocks are probable Ordovician argillites and greywackes, followed by Silurian quartzite, shales, and limestone.* These latter rocks occupy only a small area. The Ordovician strata are much intruded by granite and other igneous rocks, and contain many auriferous lodes. Tertiary conglomerates, shales, sandstones, limestones, and calcareous claystone overlie the Palæozoic rocks with strong unconformity. The youngest rocks of the county consist of glacial and fluviatile gravels, the latter found principally in the central valley. Exposures of Silurian limestone are confined to a narrow zone east of Reefton, seven miles in length, but are not continuous through this belt. Outcrops may be seen in the Waitahu and Inangahua valleys, and in Murray, Lankey, Rainy, and Deep creeks. Of these the outcrops in the Inangahua Valley and in Lankey Creek are most likely to be of commercial importance. In the former locality, five miles south-east from Reefton, limestone largely formed of corals, and at least 200 ft. thick, forms a bluff on the roadside. It dips steeply to the south-west in this locality (60° or more). A quarry was opened here a few years ago in order to supply the limestone required in the smelting of pyritic concentrates of the Progress battery, but owing to the early suspension of smelting little rock was used. Mr. Thomas Watson has successfully burnt this limestone in a low kiln, and used it on his farm, which is about two miles farther up the Inangahua Valley. The rock is not of uniform quality, and the analyses quoted below probably represent better material than the average stone of the quarry-face. The only fairly complete analysis that has been found is the following:—

Silica	7·55
Iron oxide and alumina	2·12
Lime	48·70
Magnesia	0·85
Phosphoric anhydride	0·25
Carbon dioxide	38·50
Water and organic matter	1·00
Alkalies and undetermined	1·03
	100·00
Calcium carbonate, equivalent to CO_2 (per cent.)	87·50
Quicklime (CaO) in calcined stone (per cent.)	80·50

Reference.—From Crushington, forwarded by Inangahua Farmers' Union. Dom. Lab. 46th Ann. Rep., 1913, p. 14. Lab. No. C 673/2. Composition of calcined stone is also given. A sample of limestone taken by Dr. J. Henderson from the quarry mentioned above was found to contain 84·81 per cent. of carbonate of lime (Dom. Lab. 48th Ann. Rep., 1915, p. 19; and N.Z. Geol. Surv. Bull. No. 18, 1917, pp. 221–22. Lab. No. E 746).

In 1916 Mr. E. F. Lockington forwarded to the Dominion Laboratory a sample of limestone (probably of Silurian age) from the Waitahu River which contained 91·83 per cent. of calcium carbonate and 0·09 per cent. of phosphoric anhydride (P_2O_5). (Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 624.) The analyst remarks, "This limestone, although of good quality for agricultural purposes, is not sufficiently pure to be profitable for the manufacture of carbide."

Further information concerning the Silurian limestone of Inangahua County will be found in N.Z. Geol. Surv. Bull. No. 18, 1917, pp. 73 *et seq.*, 221, 222, 223, &c.

Limestone of Tertiary age is abundant in Inangahua County. The high broken tableland south-westward of Inangahua Junction consists of limestone and calcareous sandstone in thick massive layers. These rocks extend southward along the eastern flank of the Paparoa Range as far as Stony River, a distance of over thirteen miles from the northern end of the county. Much of the area is in Buller County (see p. 187). The width of the exposure decreases from north to south, and the number and thickness of the limestone layers also diminish. Near Inangahua Junction the best stone of this belt is not conveniently situated for quarrying, for it occurs in the upper portion of the strata at a height of from 600 ft. to 800 ft. above the river. (See also reports by Messrs. A. McTaggart and H. Dickson quoted on p. 210.) A hard band of limestone at least 12 ft. thick and of good quality outcrops on the Westport Road close to the Inangahua Junction, at a point 100 chains north of Inangahua Junction Railway-station. The remains of a kiln may be seen at this spot. An analysis of the limestone is given below.

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* Usually considered to be of Devonian age, but Mr. W. S. Dun and others believe that the fossils indicate a Silurian age.

In the bed of the first small creek north of Landing Bridge, and about 10 chains from the railway, limestone overlain by thick beds of sandstone is exposed. The amount of stripping required in this locality is too great for cheap working, while the rock, as judged by its appearance, is impure, and unlikely to contain more than 60 per cent. of calcium carbonate. High-grade limestone occurs south of the Landing Bridge in several of the streams draining from the Paparoa Range, but the absence of roads and of a bridge across the Inangahua prevents any immediate use of the stone being made. Hunt and Fletcher creeks, analyses of samples from which are quoted below, are in this locality.

Other deposits of Tertiary limestone in Inangahua County are small, and of no present value. Highly inclined arenaceous limestone of unknown thickness outcrops in Burk Creek, about two miles by road north of Capleston (Boatman's). A sample from this locality, obtained by Mr. A. McTaggart, contained 67·3 per cent. of calcium carbonate (Lab. No. 96—Agricultural Laboratory). Limestone containing numerous fragments of granite and other rocks is exposed in Rough Creek, a stream entering the Inangahua eight miles south-east of Reefton. The stone is obviously low grade, and this, together with the distance of the deposit from any road, makes it improbable that it will be worked for agricultural lime.

Analyses of Inangahua Tertiary limestones are set out in the following table :—

	(1)	(2)	(3)	(4)	(5)	(6)
Silica	13·20	14·15	1·70	6·36	2·05	9·13*
Iron oxide and alumina	1·92	4·28	0·53	1·59	1·09	..
Lime	46·07	43·62	53·42	50·78	52·95	49·65
Magnesia	0·24	0·71	0·53	0·82	0·48	..
Phosphoric anhydride	0·26	..	..	0·05	0·06	..
Carbon dioxide	35·70	33·96	42·36	39·60	42·00	39·01
Water and organic matter ..	1·25	2·57	0·54	0·56	0·50	..
Alkalies and undetermined ..	1·36	0·71	0·92	0·24	0·87	..
	100·00	100·00	100·00	100·00	100·00	..
Calcium carbonate, equivalent to carbon dioxide (per cent.) ..	81·14	77·2	96·3	90·00	95·45	88·66
Quicklime (CaO) in calcined stone (per cent.)	73·09	68·7	93·6	84·87	92·08	81·4

References.—(1) Probably from basin of Fletcher Creek. Forwarded by Inangahua Farmers' Union, per Secretary, Agricultural Department. Dom. Lab. 46th Ann. Rep., 1913, p. 14; and N.Z. Geol. Surv. Bull. No. 18, 1917, p. 222. Lab. No. C 673/1.

(2) Average argillaceous limestone below gorge, Hunt Creek. Dom. Lab. 48th Ann. Rep., 1915, p. 19; and N.Z. Geol. Surv. Bull. No. 18, 1917, p. 222 Lab. No E 470.

(3) Best band of limestone in gorge, Hunt Creek. Same reference as No. 2. Lab. No. E 471.

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* Insoluble in acid.

(4) From Totara Flat. Forwarded by Director of Fields, Department of Agriculture. Same references as No. 1. Lab. No. C 866. Omission of " water and organic matter " in published analysis rectified. " This sample may have been taken from a small outcrop in Fitzgerald Creek, Waiwhero S.D." (N.Z. Geol. Surv. Bull. No. 18, p. 222.) Totara Flat and Fitzgerald Creek are in Grey County, but the analysis is conveniently inserted here.

(5) Forwarded by Inangahua Farmers' Union, per Secretary, Agricultural Department. Exact locality not stated. Dom. Lab. 46th Ann. Rep., 1913, p. 14. Lab. No. C 673/3. It is unfortunate that no nearer indication of the locality of this high-grade limestone than the address " Cronadun " is given.

(6) From 12 ft. layer near Inangahua Junction, on road to Westport, 100 chains north of railway-station. Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 1817/1. Sample taken by Dr. J. Henderson in 1916.

The following analyses of limestone from Inangahua Junction are quoted by Mr. A. McTaggart in a report addressed to Mr. W. B. Auld, Secretary of the Lime Conference, Reefton, and dated 19th June, 1917 :—

Laboratory Number.	Sample Number.	Calcium Carbonate ($CaCO_3$). Per Cent.	Laboratory Number.	Sample Number.	Calcium Carbonate ($CaCO_3$). Per Cent.
83	1	73·5	89	7	74·8
84	2	73·9	90	8	74·3
85	3	73·0	91	9	80·1
86	4	69·6	92	10	66·8
87	5	69·0	94	13	73·9
88	6	81·8	95	14	74·0

Most of the samples were obtained from a limestone escarpment situated in fairly dense bush about 1 mile 70 chains from the Inangahua Railway-station and 650 ft. above the road. The others represented material that had fallen from the top of the hill above—namely, Rose Mount (1,307 ft.). The land in this locality is privately owned.

Mr. H. Dickson, Resident Engineer, Public Works Department, Greymouth, in a report dated 8th May, 1917, states that the escarpment is about 30 chains from the road (to Westport). A three-rail incline tramway would probably be the best means of getting stone down to a proposed kiln. The other accessories required would be a shoot from the quarry to the top of the tram, shoot and hopper at the bottom, and a branch road from the main road to the kiln. The total cost of tram (timber rails), road, shoots, hopper, three trucks, wire rope and brake gear, would be about £650. The cost of transporting limestone to the kiln would be about 1s. per ton. The cost of carting lime to the railway-station, with coal for kiln as back loading, would be about 2s. 6d. per ton. The proposal to erect a kiln has been condemned on account of the somewhat poor and variable quality of the limestone (66·8 to 81·8 per cent.), but if the limestone were ground the cost of transport per ton would remain much the same.

The following rough estimate of the cost of ground limestone delivered on trucks at Inangahua Railway-station, though not likely to be accurate, may be of some use as a guide to probable costs :—

	Per Ton. s.	Per Ton. d.
Breaking limestone at quarry	3	0
Transport to crushing plant	1	0
Drying stone	0	6
Crushing (say, 40 tons per day)	2	0
Bagging and weighing (bags not included)	1	0
Transport to railway	2	6
Total working-cost	10	0
Depreciation and repairs (£400 per annum) on output of 12,000 tons	0	8
Interest on capital (say, £3,250) at 5 per cent.	0	3¼
Office expenses (management, &c.), say	0	2¾
Contingencies (say, £150 per annum)	0	3
Grand total	11	5

If the output, owing to lack of demand, were less than that anticipated—namely, 12,000 tons per annum—or if the demand were intermittent, then the total cost of 11s. 5d. per ton of ground rock as estimated above would be increased.*

The capital expenditure of £3,250 would be distributed somewhat as follows:—

	£
Preliminary expenses (surveying, clearing ground, opening quarry)	200
Tram (iron rails at pre-war prices), &c.	1,000
Drying plant (furnace, revolving cylinder, &c.)	500
Rock-breaker and fine crusher	500
Buildings, excavation, &c.	500
Oil-engine, belting, dynamo, weighing-machine, &c.	300
Contingencies	250
Total	£3,250

Further information concerning the Tertiary limestone of Inangahua County will be found in N.Z. Geol. Surv. Bull. No. 18, 1917, pp. 83 *et seq.*, 221 *et seq.*

Summary of Limestone Resources, &c.

Although Inangahua County contains a great deal of limestone, much is of poor quality, and is suited for the manufacture of cement rather than of quicklime. The bands of high-grade limestone are for the most part in localities that are remote or difficult of access. The bulk of the arable land of the county is in the central valley, close to the railway; and probably for many years the farmers will draw most of their supplies of quicklime or slaked lime from outside sources, perhaps from Hodson Creek, near Ross, where a lime-kiln has lately been built. The most suitable site for a lime plant in the county appears to be Inangahua Junction. Although some of the rock here can perhaps be successfully calcined, its quality is uneven, and pulverization is rather to be recommended.

Means of Transport.

A railway enters Inangahua County from the south, and runs through the central valley to Inangahua Junction in the north. Southward this railway gives communication with the ports of Greymouth and Hokitika. It extends also to Ross, near which is a promising limestone deposit described on a later page. The main road of the county passes through the central valley, close to the railway. A branch down the Lower Buller Gorge connects with the port of Westport. Other important roads are those passing up the Inangahua Valley south-east of Reefton, and giving communication from the central valley to the mining districts of Globe Hill, Big River, and Blackwater.

Literature.

A considerable part of Inangahua County has been geologically surveyed in detail, and the results are embodied in N.Z. Geol. Surv. Bull. No. 18, 1917, "The Geology and Mineral Resources of the Reefton Subdivision, Westport and North Westland Divisions," by J. Henderson. On pages 7–13 of that bulletin will be found a complete list of the literature dealing with Inangahua County.

13. GREY COUNTY.

The geology of Grey County is similar to that of Buller and Inangahua counties, but schists of unknown Palæozoic age are well developed in the eastern part of the county on the western side of the Southern Alps. Towards the crest of the Alps greywackes and argillites that may be of Early Mesozoic age appear. Morainic material is much more prominent than in Inangahua County. The Tertiary rocks, as in Buller County, fall into two series, one of Eocene the other of Miocene age. The Eocene rocks, as in Buller County, contain valuable seams of bituminous coal. Above the coal horizon is a sandstone which in places, especially north of Dunollie, is so calcareous that caves and underground stream-channels have been formed in it by the action of water. The limestone of the county, however, is practically entirely of Miocene age. The quantity is large, but the quality varies, and there is no deposit of good grade well situated for immediate exploitation.

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* In practice post-war conditions are likely to increase the capital expenditure and other costs at least 25 per cent.

The limestone in the southern part of Buller County extends into Grey, and reaches to within three miles of Barrytown. It forms sea-cliffs 100 ft. high north of the Punakaiki River, but farther south is concealed by younger strata, except inland along the foot of the mountains, where it has been upturned by crustal movements. As a whole the rock is decidedly arenaceous, but in places fairly pure layers are found.

From Point Elizabeth to Cobden, a distance of four miles and a half, limestone forms the greater part of the Rapahoe or Twelve Apostles Range, which skirts the coast and reaches a height of 1,100 ft. or more. Some of the islets close to Point Elizabeth are formed of the same rock. The limestone strikes nearly north and south, and dips seaward at angles varying between 20° and 30°. It therefore dips with the western slopes of the hills. On their eastern side it forms high cliffs. The Greymouth Harbour Board has quarries at Cobden and on the south side of the Grey River, from which stone for the breakwater is obtained. The limestone in these quarries is in thick layers, separated by more argillaceous bands. It varies in quality, but most is both arenaceous and argillaceous. The thickness of the limestone at Cobden and Greymouth, including the argillaceous or claystone bands that become more and more prominent in the lower horizon, is almost or quite 700 ft. Elsewhere, as will be seen from the paragraph below, the thickness is much less. At Point Elizabeth, partly owing to erosion, the limestone may be less than 150 ft. thick.

The Rapahoe Range or Cobden limestone is continued south of the Grey River by the limestone of Peter Ridge. This outcrops continuously on the crest and slopes of the ridge as far south as Limestone Diggings. The dip is at moderate angles to the west or south-west. The thickness diminishes from Greymouth southwards till at Kakawau Peak it is probably well under 250 ft. A steeply dipping band of limestone from 100 ft. to 200 ft. thick extends along the western side of Stillwater Valley from Lisbon and Sylvester creeks south-westwards. South-east of Kakawau it joins the Peter Ridge belt. This disposition of the limestone in the district south-east of Greymouth is due to the geological structure, which is that of an unsymmetrical anticline striking south-westward, and also pitching downward in that direction. The consequence of this pitch is that northwards of Marsden the limestone disappears under younger rocks. Impure limestone is seen again, however, on the south bank of the New River below Marsden, the outcrop being due to the New River having eroded its valley to the level of the anticlinal crest of the limestone stratum. Again, about two miles and a half to the south-west, owing to a slight upward bulge of the anticlinal crest, good limestone is exposed in the gorges of Fireball and Tansey creeks, near the Taramakau River. The limestone here is well bedded, and has moderate but irregular dip. Its thickness exceeds 100 ft.

Bores drilled in search of petroleum at Kotuku have shown that excellent limestone, from 110 ft. to 123 ft. thick, exists some hundreds of feet below the surface. Salt water issuing from some of the bores has deposited a moderate amount of calcareous sinter on the surface. A bore at Kaimata, less than three miles to the westward, has shown that the limestone is there represented by 64 ft. of calcareous sandstone and 61 ft. of highly calcareous claystone, which underlies the calcareous sandstone.

An isolated patch of limestone, apparently of fair quality, forms Knoll Point on the south shore of Lake Brunner. This locality is six miles south by west from Kotuku Railway-station, about seven miles from the Kotuku oil-bores, and less than eight miles from the Kaimata oil-bore. Seven to seven and a half miles west-south-west of Knoll Point impure pebbly limestone outcrops in Deep and Clear creeks, and on the ridge between. This material is of possible value only because of its proximity to the Taramakau or Hohonu Settlement, on the north-east side of the Taramakau River.

Thin bands of limestone, some several feet thick and of excellent quality, occur in the sandstones and claystones of Blackwater and Bray creeks, small streams entering the Grey River south-west of Ngahere. Similar bands occur in other streams to the south-west of Bray Creek, but in no case do they have any present economic value. An outcrop of broken impure limestone on the west side of the Otira Railway-line, half a mile or less southward of Stillwater Junction, may belong to the same horizon as these bands, or to the somewhat higher one of the Cobden limestone. Calcareous rocks outcrop also on the railway to Reefton, a quarter of a mile east of Stillwater Railway-station.

A band of foraminiferal limestone occurs near Greymouth at a somewhat higher horizon than the Cobden limestone. It is best seen near trig. station FC, where it outcrops at a height of 300 ft. over an area of roughly 1 acre, and is 18 ft. to 20 ft. thick or more. The bed dips at 18° to 20° to the westward. It has been found a short distance to the southward, and, as shown by débris, probably extends as far south as the Marsden district, except where it has been removed by denudation. As seen near trig. FC the upper part of the foraminiferal limestone is of fairly good quality. The lower part, however, contains many inclusions of greenish clayey material, and is not sufficiently rich for burning. The remains of an old kiln may be seen down the slope to the north; and here limestone from the outcrop above was successfully calcined, it is said, many years ago. Considerable attention has been given to this outcrop, owing to its position being convenient and its quality better than that of most of the limestone in the neighbourhood of Greymouth.

A quarry could be opened either on the western face or the northern face. Mr. H. Dickson, Resident Engineer, Public Works Department, Greymouth, has estimated that the cost of making shoots and aerial or incline tram road to connect with constructed road, together with cost of wire ropes, brake gear, and three trucks would be £600. The cost of transport to a proposed kiln at the foot of the hill would be 1s. per ton, and of carting lime to the railway-station, 2s. per ton, including cost of carting coal as a back loading to the kiln.

Additional Details; Analyses of Limestone; Discussion of Quality, &c.

In the years 1909–10 representative samples of limestone were collected by P. G. Morgan from various parts of the Greymouth district. Analyses of these are given in full in N.Z. Geol. Bull. No. 13, 1911, page 94, and only the calcium-carbonate and silica contents are repeated here. Somewhat arenaceous nearly white limestone from Point Elizabeth contained 14·05 per cent. of silica and approximately 80·26 per cent. of calcium carbonate (by addition of CaO and CO_2). (Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 440.) A sample from one of the most northerly points on the summit of the Rapahoe Range was slightly more siliceous: it contained 16·05 per cent. of silica and 77·80 per cent. of calcium carbonate. (Dom. Lab. 44th Ann. Rep., 1911, p. 19. Lab. No. A 441.) No sample was taken from the Greymouth Harbour Board's quarry at Cobden. The limestone here is of a pale-yellowish colour, soft, arenaceous and argillaceous, and not of good quality. At a lower horizon, near the railway-bridge over the Grey River, where there is a cave, described by H. N. McLeod, the limestone is of better quality.

On the south side of the Grey River the Greymouth Harbour Board's quarry exposes a section of several hundred feet of limestone. This is in general similar to that of the Cobden quarry just across the river, but there is a horizon where the stone appears to be of somewhat better quality. A general sample taken in 1910 contained 18·45 per cent. of silica and approximately 75·25 per cent. of carbonate of lime. (Bull. No. 13, p. 94; and Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 847. Wrongly ascribed to Cobden, probably owing to its being labelled "Cobden limestone.") In the latter part of 1916 a representative sample was selected west of the road-bridge over the Grey River by Dr. J. Henderson from the most promising portion of the limestone face, consisting of 20 ft. of calcareous beds 6 in. to 3 ft. thick, separated by argillaceous layers. This sample contained 16·87 per cent. of matter insoluble in acid, 79·61 per cent. of calcium carbonate, and 1·05 per cent. of moisture and organic matter. (Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 1817/2.) A little south of the Greymouth quarry, limestone from about the same horizon as that of the sample just mentioned has been quarried and burnt in a kiln with indifferent results.

The following six analyses made by Skey of the limestone at Greymouth may be quoted. Probably all the samples came from the Harbour Board's quarries or their immediate vicinity.

	(1)	(2)	(3)	(4)	(5)	(6)
Calcium carbonate	75·67	68·12	75·91	88·12	78·51	64·74
Magnesium carbonate	2·20	3·54	1·82	1·71	1·86	2·21
Alumina	1·41	2·22	0·72	0·81	1·32	1·41
Iron oxide	Traces	2·71	1·11	Traces	0·49	0·57
Matter insoluble in acid (fine sand, &c.)	19·83	22·01	19·61	8·24	16·63	26·22
Soluble silica	0·61	1·08	0·60	0·80	0·82	1·84
Water	0·28	0·32	0·23	0·32	0·37	1·01
	100·00	100·00	100·00	100·00	100·00	98·00
Quicklime (CaO) in calcined stone (per cent.)	64·8	56·1	63·0	82·1	68·6	..

Reference.—Six limestones from Greymouth, forwarded by the Royal Commission on Local Industries (or Industrial Commission). Col. Mus. and Lab. 15th Ann. Rep., 1880, pp. 34–35. Lab. Nos. 2756/1–6. There is an error of 2 per cent. in the tabulation of No. 6.

A representative sample of greyish-brown foraminiferal limestone from the outcrop near trig. station FC, collected in 1910 by P. G. Morgan, contained 10·96 per cent. of silica and approximately 81·57 per cent. of calcium carbonate. (Bull. No. 13, p. 94; and Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 1148.) In 1916 Dr. J. Henderson took a similar sample, which yielded on analysis 84·82 per cent. of calcium carbonate and 9·46 per cent. of matter insoluble in acid. (Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. 1817/3. Locality wrongly stated as "Easson's.") In March, 1917, the outcrop was sampled by Messrs. A. McTaggart and P. G. Morgan. The three samples taken yielded 86·4, 71·8, and 83·3 per cent. of carbonate of lime respectively. The first and third samples represented the upper portion of the deposit, and the second sample the somewhat poor lower portion. The weighted average is 79·6 per cent.

The arenaceous limestone of Sylvester Creek, Stillwater Valley, is nearly white in colour, and as sampled in 1909 near the track-crossing contains 12·95 per cent. of insoluble matter and 82·50 per cent. of calcium carbonate. (Dom. Lab. 43rd Ann. Rep., 1910. p. 12; Lab. No. 306; and Bull. No. 13, 1911, p. 94.)

The limestone in the gorges of Fireball and Tansey creeks, near Kumara, but on the north side of the Taramakau River, is a light-coloured flaggy stone suitable both for building purposes and for burning into lime. It is a fairly good limestone, and hardly deserves the adjective "arenaceous" applied to it in Bull. No. 13. The analysis of a sample taken in 1909 shows 7·00 per cent. of silica and 88·30 per cent. of calcium carbonate. (Dom. Lab. 43rd Ann. Rep., 1910, p. 12; Lab. No. 305; and Bull. No. 13, 1911, p. 94.) The calcined stone would contain about 84·7 per cent. of quicklime (CaO). A road from Kumara via Cape Terrace reaches Tansey Creek, and continues as a horse-track till it joins the road from Nemona to Cameron's, which in 1909–10 was a horse-track, but is now in part a road suitable for wheeled traffic.

The impure limestone of Clear and Deep creeks, near the Taramakau Settlement (Hohonu), was discovered by P. G. Morgan and J. A. Bartrum, of the Geological Survey, in December, 1908. It is interbedded with conglomerate, claystone, and sandstone. A sample from Deep Creek, taken at that time but not analysed until eight years later, is represented by No. 2 below, whilst No. 1 represents a sample from Clear Creek collected in 1916 by Dr. J. Henderson.

	(1) Per Cent.	(2) Per Cent.
Moisture lost at 100° C.	0·74	0·33
Matter insoluble in acid	22·77	29·55
*Lime (CaO)	39·58	36·32
*Equivalent to calcium carbonate ($CaCO_3$)	70·68	64·86

References.—(1) From scattered outcrops, Clear Creek (1916). Dom. Lab. 50th Ann. Rep., 1917, p. 21. Lab. No. G 1817/4.
(2) From Deep Creek (1908). Same reference as No. 1. Lab. No. G 1817/5.

Dr. Henderson reports that on the spur to the north of Clear Creek the limestone appears to be of better quality than that in the creek. The outcrops in Clear Creek are about 40 chains from a good road, and there would be no difficulty in forming a branch road to their vicinity.

The analysis of the Kotuku limestone, made on a sample of drill-core obtained in 1909 (stated to come from the Lake Brunner Oil Company's No. 2 bore), shows that the stone is very high grade. Silica is 3·25 per cent. and calcium carbonate 93·90 per cent. (Bull. No. 13, 1911, p. 94; and Dom. Lab. 43rd Ann. Rep., 1910, p. 12. Lab. No. 307.) In 1910 samples from the Taylor Syndicate's A2 bore at Kotuku were tested in the Dominion Laboratory, with the following results:—

	(1) Per Cent.	(2) Per Cent.
Silica	23·70	17·75
Calcium carbonate	62·50	72·78
Magnesium carbonate, not more than	0·15	0·10

References.—(1) From depth of 425 ft. to 429 ft., A2 bore. (2) From depth of 430 ft. to 435 ft., A2 bore. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. Nos. A 848/1, 2.

The samples were much contaminated by material from a higher horizon, and were taken in order to ascertain if the bore had entered limestone. Other bores at Kotuku have yielded limestone cores of quite as good quality as that of which the analysis is quoted above. The samples obtained are almost white in colour, soft, and porous.

The limestone bands in Bray and Blackwater creeks, near Blackball, are of greyish colour, and at first sight appear gritty. They are, however, oolitic stones of considerable purity, as is shown by the analysis of a sample collected late in 1909. This shows 2·02 per cent. of silica and 94·12 per cent. of calcium carbonate (Bull. No. 13, p. 94; and Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 438).

The limestone of Mulligan and Brown creeks, small streams draining into Saltwater Creek near Welshman's, is in part of good quality. Saltwater Creek itself issues from a large cave in flaggy limestone of fairly good appearance. No samples of the stone from Saltwater Creek and its tributaries have been taken, but the localities are not many miles from the railway, and some day will deserve attention. Kakawau Peak is another somewhat remote locality where the limestone, 200 ft. to 250 ft. thick, is flaggy and apparently of good quality.

At Point Elizabeth, in the calcareous mudstone below the limestone that forms the main part of Point Elizabeth, there are one or two thin bands of limestone. The calcareous claystone found above the Cobden or main limestone horizon in those localities, where it is not hidden by gravels or has not been removed by erosion, is locally known as the "Blue Bottom," and in many places contains calcareous concretions. The Kaiata mudstone, of Eocene age, is in places highly foraminiferal, and becomes a marl—for instance, near the coast south of the Nine-mile Bluff.

An analysis of limestone from the neighbourhood of Blackball has yet to be cited. The sample it represents may have come from a band of limestone in one of the small streams south of Blackball. This analysis is given by B. C. Aston, and is as follows :—

Insoluble matter	6·46
Alumina and iron oxides	1·60
Calcium carbonate	91·07
	99·13
Quicklime (CaO) in calcined stone (per cent.)	87

Reference.—Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 330. Analyst's No. and date : K 2953 ; 1909.

In Fitzgerald Creek, a small branch of Moonlight Creek, a small outcrop of fault-involved limestone is visible. The analysis (No. 4) of limestone from Totara Flat given on page 209, under Inangahua County, and supposed to be really from Fitzgerald Creek, ought to be quoted here, for both localities are in Grey County. The analysis shows 6·36 per cent. of silica and 90·00 per cent. of calcium carbonate.

The following two analyses represent samples which are attributed to Brunner, but must have come from outcrops some miles away :—

	(1)	(2)
Matter insoluble in acid	5·75	21·80
Alumina	1·39	3·01
Iron oxides	1·12	0·68
Lime	50·23	39·52
Magnesia	0·81	0·36
Carbonic anhydride	38·90	30·40
Moisture and organic matter	1·80	4·23
	100·00	100·00
Calcium carbonate ($CaCO_3$) equivalent to CO_2 (per cent.)	88·41	69·01

Reference.—From an unspecified locality. Forwarded by Tyneside Proprietary Company. Dom. Lab. 50th Ann. Rep., 1917, pp. 20, 37. Lab. Nos. G 336/1, 2.

Summary of Limestone Resources, &c.

As already stated, Grey County contains large quantities of limestone, but it varies considerably in quality. The limestone at Greymouth and Cobden has an ideal situation so far as facilities for quarrying and distributing it are concerned, and the quantity is practically unlimited, but on the whole it is decidedly of low grade, and even the best bands are fit only for pulverization. This limestone, however, though rather soft for that purpose, has been extensively quarried in order to form the moles at the entrance to the Grey River. It has also been used to a small extent as a building-stone, and some very poor lime (from the agricultural point of view) has been made from it.

The upper portion of the foraminiferal limestone band near trig. FC could be burnt in a kiln. The band as a whole is suitable for making cement or for pulverization. The quantity, however, is small, and not much more than 60,000 tons of good grade can be quarried without underground mining. The locality is only 20 chains from a road, and three-quarters of a mile from the Greymouth Railway-station. In time to come Stillwater Valley, Kakawau Peak, Saltwater Creek valley, Fireball Creek, or other localities may become sources of lime. Exploitation of these deposits will necessarily be preceded by some exploration, and especially by sampling. At present Grey County must look to the limestone now being worked near Ross for high-grade lime or pulverized limestone. From Ross to Greymouth by rail is thirty-eight or thirty-nine miles, and to Totara Flat, in the north of the county, another twenty-seven miles. From Ross to the agricultural land near Rotomanu, Poerua, Inchbonnie, &c., via Greymouth and Stillwater Junction, the railway distances are from sixty-nine to seventy-five miles.

Means of Transport, &c.

The settled portions of Grey County have good means of communication. From the port of Greymouth railways radiate to the various coal-mines, to Reefton, Otira, and Ross. The limestone of Knoll Point, if it were worked, could easily be taken across Lake Brunner to Moana Railway-station. The county is fairly well roaded, and in a few years' time will have little to complain of in that respect.

Literature, &c.

The greater part of Grey County has been geologically surveyed in detail. The results are embodied in the following three bulletins:—

N.Z. Geol. Surv. Bull. No. 1, 1906: "The Geology of the Hokitika Sheet, North Westland Quadrangle," by J. M. Bell and C. Fraser. This deals with a very small area in Grey County—namely, the southern part of the Hohonu Range and some adjoining river-flats.

N.Z. Geol. Surv. Bull. No. 13, 1911: "The Geology of the Greymouth Subdivision, North Westland," by P. G. Morgan.

N.Z. Geol. Surv. Bull. No. 18, 1917: "The Geology and Mineral Resources of the Reefton Subdivision," by J. Henderson.

The lists of literature given in these three bulletins, more especially No. 13, indicate practically all the publications dealing with the geology of Grey County.

14. WAIPARA COUNTY.

Waipara County is a long wedge-shaped area, reaching from Harper's Pass at the head of the Hurunui to the east coast of the South Island. The principal rocks of the western, mountainous, almost unsettled portion are old Mesozoic greywackes and argillites. The intermontane basins are covered by fluviatile gravels, or contain lakes, such as Sumner and Taylor. A little morainic material is also present. The eastern part of the county, in addition to areas of old Mesozoic rocks, contains a considerable variety of Cretaceous and Tertiary conglomerates, sandstones, limestones, claystones, &c.

Part of the Hurunui Plain is in the county; and near Waipara a flat area that forms the northernmost part of the famous Canterbury Plain begins.

The principal limestones of Waipara County are the Amuri limestone of supposed Upper Cretaceous age, and the Weka Pass stone, which is now generally admitted to be of Tertiary age, though in all the localities where it has been examined it appears to rest on the Amuri limestone without angular unconformity. For this reason some geologists think that there is no unconformity between the two limestones. Others admit a slight stratigraphical break or non-sequence, and others, including the writers of this bulletin, consider that there is a true disconformity and that it denotes a considerable time-interval.

The Amuri limestone and Weka Pass stone may be best observed near Waikari and at Weka Pass. On account of their close association in this district they are most easily described as a unit. The two limestones occupy an area of over two square miles south of Waikari. From this area a long strip extends eastward some distance south of the Waikari Valley Road for many miles. It reaches Moore's Hill South and probably also Moore's Hill North. The dip is at moderate angles to the south. A strip of Weka Pass stone occurs four to five and a half miles east of Waikari, north of Sealey's Direct Road (which is here the main highway) and south of the Waikari Valley Road (Mr. Turner's land). This strip has a southerly dip of about 20°. The visible thickness is 50 ft. to 80 ft. Again, a long strip of limestone with south-easterly dip extends from the railway-line north of Weka Pass for at least ten miles to the south-west. It passes west of North Dean, crosses the Waipara River into Kowai County, and continues beyond Boby's Creek.

Various isolated patches of Amuri limestone and Weka Pass stone occur west of Waikari on an education reserve, on Mr. Holland's land, west side of Razorback Road, &c.

On the south bank of the Hurunui, about a mile from the sea, the Amuri limestone is over 50 ft. thick, and has a dip of 10° to the west.

The Amuri limestone forms high cliffs on the coast south of the Blyth River. In this locality it dips gently to the south-east, and the thickness is at least 300 ft. The rock is beautifully white, compact in texture, and well jointed, but much disturbed by slips and faults (Speight and Wild, 1918). The Amuri limestone is again seen in a creek near Stonyhurst homestead. According to McKay it appears as a narrow belt forming part of a low range between the south-west branch of the Motunau and a tributary creek coming from the east and draining the coast range to the south-east of the junction (1881 report, p. 114). In the Motunau River at two miles from the sea it is 300 ft. thick. Between the Mount Cass Range and the lower part of the Omihi Valley there is a range of hills on which the Amuri limestone dips to the north-east. Patches of Amuri limestone or Weka Pass stone occur on the summit of the Cass Range east of Waipara. Thus limestone occurs almost continuously in the coastal range from the Hurunui River to the Waipara.

In the localities mentioned the Amuri limestone is generally from 60 ft. to 300 ft. thick, but in Boundary Creek only 20 ft. was seen by Speight and Wild. The thickness is therefore commonly much less than that observed in Awatere and Kaikoura counties. It is a close-grained nearly white rock, which is usually hard, but in many places is shattered, and in some fault-crushed. It gives rise also to deposits of soft limestone, which will be more particularly mentioned later. The lower part of the Amuri limestone is argillaceous, and in places is a marl or calcareous claystone rather than a limestone, so that its thickness is difficult to define. The upper portion is inclined to be arenaceous. Generally it is sharply separated from the Weka Pass stone by a layer of soft calcareous glauconitic sandstone, containing in many places phosphatized pebbles of Amuri limestone, and this layer gradually passes into the typical Weka Pass stone, which is a sandy limestone, softer, coarser-grained, and less jointed than the Amuri limestone; but there are localities—for example, near the Waipara River above Mount Brown—where the transition from Amuri limestone to Weka Pass stone appears gradual. The Weka Pass stone between Waikari and the Waipara River has a thickness approaching but not exceeding 100 ft.

Speight states that limestone can be traced from the northern part of the Hurunui basin, but not continuously, across the Hurunui to the flanks of Mount Mason. This limestone is not seen on the south side of the Hurunui basin, but reappears farther west, and the outcrop follows round the western end of the Trias-Jura mass forming the Mount Alexander Range, and joins on to the Weka Pass stone near Waikari. (Trans., vol. 47, 1915, p. 347.) The amplification of these and other statements not quoted, with the addition of an adequate map, is much to be desired.

In addition to the two limestones just described, Waipara County has a third limestone, younger than the Weka Pass stone, and known as the "Mount Brown limestone," owing to its forming part of the Mount Brown beds, which are typically developed in the hill of that name south of the Waipara River (Kowai County). This is a rubbly shelly rock, occurring in two or three somewhat irregular bands separated by less calcareous layers. It has already been mentioned, though not under that name, as exposed along the north-western edge of the Waiau-Hurunui Plain. It continues southward of the Hurunui into Waipara County, and outcrops almost continuously on the south-west margin of the plain. Two bands of rusty-coloured rubbly limestone, the upper 25 ft. to 30 ft. thick, the lower 50 ft. to 60 ft., separated by 60 ft. to 95 ft. or more of calcareous sandstone, form prominent escarpments at Mount Brown, and extend north-eastwards for some miles towards Weka Pass. At Weka Pass and Mount Donald the rubbly limestone appears to be scattered through a considerable thickness of strata (see Park, 1888 report, p. 32). Rubbly limestone bands of the Mount Brown Series are seen five miles west of Waikari, near the locality known as "The Pyramids." These bands are not very thick. They dip steeply with the associated strata at angles of 50° to 80° to the west.

Small outcrops of the Mount Brown beds appear east of Waikari Cemetery, where they have been quarried for roadmaking purposes. Rubbly shelly rock occurs in thin beds, alternating with softer material. The dip is 25° to the south, which must bring the beds in contact with the Amuri limestone and associated beds that outcrop in that direction. Consequently a fault is bound to intervene.*

According to McKay the Mount Brown limestone is well developed in the northern part of the Mount Cass Range. It occupies a small area in the upper basin of the Motunau River, and appears as isolated patches on the coastal range south-west of the mouth of the Motunau, and on Mount Friday, north-east of Boundary Creek, a few miles from Stonyhurst. The Mount Brown beds in that locality, McKay states, have suffered great denudation (1881 report, pp. 112–13). In the hills south-east of Waipara the Mount Brown limestone seems to be represented by layers of calcareous conglomerate.

Soft-limestone Deposits.

During the past few years several soft-limestone deposits have been discovered in Waipara County, and have received much attention, chiefly owing to the exertions of Mr. B. C. Aston, Chief Chemist, and Mr. A. McTaggart, Agriculturist, both of the

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* R. Speight seems to refer to this fault in Trans. N.Z. Inst., vol. 47, 1915, p. 347.

Agricultural Department. The Waipara County Council, Mr. H. H. Holland of Waikari, and others have also assisted in having the deposits investigated and developed. The soft-limestone deposits near Waikari are described by Mr. McTaggart in an article entitled "Survey Operations and Limestone Finds" in the *Journal of Agriculture*, vol. 11, No. 5, November, 1915, pages 394–400.

A few chains south of Waikari Railway-station the Waikari Council has made an excavation in limestone débris; and possibly 200 tons or more of the material has been dug and classified by means of a coarse sloping sieve, under which is a boarded surface and an arrangement for bagging the fine product. In December, 1915, when the locality was visited by one of the writers, the face showed the following section: 9 in. black soil; 6 in. to 2 ft. hard-limestone débris; 5 ft. to 7 ft. highly friable limestone débris mixed with hard fragments of various sizes, and underlain by yellowish-grey sand. The lower part of the friable material was clearly poorer in quality than the upper. The post-holes of a neighbouring fence showed that soft-limestone débris extended at least 2 chains up the slope to the south, but it was not visible a few chains to the eastward. In this direction a road-cutting exposed only a yellowish sandy débris, containing veins or patches of pure-white almost impalpably fine material resembling whiting. In January, 1918, the locality was revisited. The face then showed 10 ft. to 11 ft. of limestone débris overlain by a few inches of black soil. The material consisted largely of hard fragments, but towards the surface the lumps were somewhat friable, and more fine stuff was present. Unless the hard lumps can be conveniently used for roadmaking or some such purpose there does not seem to be much prospect of handling the soft material at this spot to advantage.

South-west of Waikari, on an education reserve (Section R. 1145), a deposit of soft limestone occurs near the foot of a slope below a limestone ridge. This has been bored to a depth of 14 ft. (only at one place), and in January, 1918, was being stripped with a view to working it. The scarcity of labour had impeded its full development up to that time.

On Mr. Holland's land, about a mile west of the education reserve, soft-limestone débris is found over a considerable area west and south-west of his house, on the slopes of a limestone-capped hill. A number of shallow test pits have been dug in the deposit, and at one place it was bored to a depth of 14 ft. without finding hard bottom. The quality is variable. Mr. McTaggart states that the first sample analysed contained about 88 per cent. of carbonate of lime on the moisture-free basis. About half a mile west of Mr. Holland's house a test pit exposes 2 ft. of soft-limestone débris of good quality, underlain by hard limestone.

Mr. McTaggart states that soft-limestone deposits occur on at least four other privately owned areas of land in the Waikari district. A small deposit of chalky débris is exposed by a railway-cutting in Weka Pass.

For some further particulars concerning Waikari soft limestone the reader may be referred to Mr. McTaggart's graphic article in the *Journal of Agriculture*. It is necessary to note that insufficient data exist to justify his statement that there are probably "millions of tons or unlimited supplies of this desirable material in the locality."

The "soft limestones" of the Waikari district are slope or talus deposits formed by the weathering and disintegration of Amuri limestone and, to a less extent, of Weka Pass stone. In general they are not so pure as the original rock, but portions appear to have become enriched in carbonate of lime. For general statements concerning the origin of soft-limestone deposits of this kind see 10th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1916, pp. 15, 17.

Analyses of Limestone.

The earliest recorded analyses of limestone from Waipara County appear to be those of samples collected by Professor James Park in 1904. They are as follow:—

	(1)	(2)	(3)	(4)
Silica (SiO_2)	22·51	34·95	14·45	7·25
Alumina (Al_2O_3)	3·92	6·44	1·03	0·66
Ferric oxide (Fe_2O_3)	2·08	2·76	0·77	0·54
Calcium carbonate ($CaCO_3$)	67·60	47·62	81·56	88·64
Magnesium carbonate ($MgCO_3$)	0·80	1·46	0·61	0·45
Calcium oxide (CaO)	0·80	1·50	..	..
Organic matter and water	2·29	3·50	1·58	2·06
Undetermined	..	1·77	..	0·40
	100·00	100·00	100·00	100·00

References.—(1) Weka Pass stone from Waikari end of Weka Pass, from cliffs on north side of stream, a few chains above railway-viaduct. Average sample selected from whole thickness of beds. Trans. N.Z. Inst., vol. 37, 1905, pp. 544–45. Col. Lab. 38th Ann. Rep., 1905, p. 10; Lab. No. 9864/1. N.Z. Geol. Surv. 9th Ann. Rep., part of Parl. Paper C.–2, 1915, p. 92. Also R. Speight and L. J. Wild, Trans. N.Z. Inst., vol. 50, 1918, p. 72.

(2) Weka Pass stone, 2 ft. above Amuri limestone. Same references as No. 1. Lab. No. 9864/4.

(3) Amuri limestone, 2 ft. below Weka Pass stone. Same references as Nos. 1 and 2. Lab. No. 9864/2. Also R. Speight and L. J. Wild, Trans. N.Z. Inst., vol. 50, 1918, p. 68.

(4) Amuri limestone. Average sample from thickness of 40 ft. Same references as Nos. 1, 2, and 3. Lab. No. 9864/3.

The exact localities of samples Nos. 2, 3, and 4 are not stated, but doubtless they were taken in the neighbourhood of sample No. 1.

In December, 1915, P. G. Morgan selected samples of Amuri limestone in the gorge of Weka Pass Creek, above the railway-viaduct. Analyses of these are—

	(1)	(2)	(3)
Silica	11·12	7·52	6·74
Alumina and ferric oxide	1·78	1·64	1·50
Lime	46·55	49·33	49·75
Magnesia	0·22	0·22	0·67
Phosphoric anhydride	0·28	0·19	0·12
Carbonic anhydride	36·41	38·49	38·76
Moisture and organic matter	1·74	1·05	1·20
Alkalies and undetermined	1·90	1·56	1·26
	100·00	100·00	100·00
Calcium carbonate (per cent.)	82·20	86·93	86·42
Magnesium carbonate (per cent.)	0·46	0·46	1·41

References.—(1) Amuri limestone at contact with Weka Pass stone (glauconitic calcareous sandstone). 9th Ann. Rep. N.Z Geol. Surv., part of Parl. Paper C.–2, 1915, p. 92. Lab. No. F 370. Also R. Speight and L. J. Wild, 1918, p. 68.

(2) Uppermost layer of Amuri limestone, in same locality and with same references as No. 1. Lab. No. F 371.

(3) Hard Amuri limestone, about 35 ft. below upper surface. Same locality and references as No. 1. Lab. No. F 372.

Other samples of Amuri limestone, taken at the same time as Nos. 1, 2, and 3 above, on analysis yielded the following results:—

	(4)	(5)	(6)	(7)
Insoluble in acid	11·75	16·97	9·30	28·20
Calcium carbonate ($CaCO_3$)	83·75	75·73	86·60	66·60
Phosphoric anhydride (P_2O_5)	0·52	1·21	0·16	0·27
	96·02	93·91	96·06	95·07

References.—(4) Pebbles of Amuri limestone in glauconitic calcareous sandstone (lowest layer of Weka Pass stone), from same locality as Nos. 1 to 3 above.

(5) Amuri limestone, near upper surface, some distance up valley (quarter mile or little more) of Weka. Pass Creek, above railway-viaduct.

(6) Amuri limestone, 30 ft. below upper surface, same locality as No. 5.

(7) Amuri limestone (argillaceous), 50 ft. to 80 ft. below upper surface, same locality as Nos. 5 and 6.

The published references to samples Nos. 4 to 7 are 9th Ann. Rep. N.Z. Geol. Surv. as already cited, and Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. Nos. F 369, 373, 374, 375.

B. C. Aston gives the following analyses of limestones and marly rocks from Waipara County :—

Locality.	Calcium Carbonate, per Cent.	Laboratory Number.	Date.	Remarks.
Scargill	53·10	F 340	1905	Very porous and friable.
Te Paka, Scargill ..	91·79	G 208	1915	
,, ,, ..	80·08	G 209	,,	
Hurunui	70·91	G 213	,,	
Wandle River ..	6·19	G 212	,,	"Papa" (? calcareous claystone).
Waikari	64·10	G 433	1906	
,, ...	50·46	G 434	,,	
,, ...	71·31	G 214	1915	Soft limestone ; 18·47 per cent. water (A. McTaggart).
,, ...	77·39	G 215	,,	
,, ...	65·47	G 216	,,	Soft limestone.
Braemyle, Waikari ..	59·39	G 223	,,	
,, ,, ..	79·40	G 224	,,	
Waikari	79·26	G 225	,,	
,, ...	60·82	G 226	,,	Soft, 19·6 per cent. water (A. McTaggart).
,, ...	69·5	G 397	,,	Soft limestone.
,, ...	43·3	G 398	,,	,,
,, ...	69·7	G 399	,,	,,
,, ...	59·0	G 400	,,	,,
,, ...	3·5	G 401	,,	Marl (calcareous limestone).
,, ...	93·9	G 402	,,	Soft limestone.
Weka Pass Road, Waikari	72·92	G 210	,,	Soft (A. McTaggart).
Weka Pass	75·61	G 211	,,	
,, ...	92·65	G 217	,,	

Reference.—Jour. Agric., No. 4, Oct., 1915, pp. 330–31. See also pp. 393–400.

F 340, from Scargill, also contained—Insoluble matter, 25·89 per cent.; alumina and iron oxides, 0·21 per cent.; magnesium carbonate, &c., 2·07 per cent.; water, &c., 18·73 per cent.

The Dom. Lab. 48th Ann. Rep., 1915, p. 21, gives nine analyses of Canterbury limestones. The samples were forwarded by the Fields Supervisor, Agricultural Department, but the localities are not stated, and therefore they cannot be assigned to any particular county. With the exception of a determination relating to a calcareous sandstone, or some such rock, the analyses show from 67·88 to 89·05 per cent. of calcium carbonate. (Lab. Nos. E 1279/1–9.)

Speight and Wild give the following analyses in their 1918 paper, page 71 :—

	(1) Per Cent.	(2) Per Cent.	(3) Per Cent.	(4) Per Cent.
Insoluble in acid	12·08	11·95	11·52	55·68
Calcium oxide or lime (CaO) ..	48·65	42·20	44·85	..
Phosphoric anhydride (P_2O_5) ..	0·16	0·45	4·09	1·34

References.—(1) Sample 2 ft. from present surface of Amuri limestone.

(2) Sample from upper 6 in. of honeycombed portion of Amuri limestone.

(3) Detached nodules of Amuri limestone lying in the Weka Pass stone a few inches above the present surface of the Amuri limestone.

(4) Lower 2 ft. of Weka Pass stone.

Summary of Limestone Resources, &c.

The eastern part of Waipara County has many large deposits of limestone, sufficient not only for its own needs but also for those of all northern Canterbury. Much of the limestone is conveniently situated close to railways, but the quality is variable. Further exploration of the limestone is desirable, and in addition a considerable amount of careful sampling is needed.

The best and most abundant of the limestone is that which has been called the "Amuri limestone." The upper 40 ft. of this stone in the Weka Pass district appears to contain on the average over 85 per cent. of calcium carbonate. The impurity is mainly sand, and the rock can probably be calcined in an ordinary kiln without difficulty. Somewhat strange to say, no evidence of the limestone in Waipara County ever having been burnt has been obtained. The Weka Pass stone is in general too arenaceous and low grade to be suitable for burning. The rubbly Mount Brown limestones are usually too impure to be of great value. They vary much in quality, and in places will be found useful. No analyses of the Mount Brown stone are certainly known to have been made,* and some sampling is therefore desirable. The so-called "soft limestone" deposits near Waikari are possibly of great potential value, but so much has been said on their behalf that a word of caution is necessary. They vary much in quality, and sufficient data from which to estimate the quantity of material carrying, say, over 70 per cent. of calcium carbonate on an air-dry basis have not been obtained in any case. It ought to be clearly understood that the deposits are not beds in the ordinary sense, but modern slope accumulations of débris from the much more ancient and comparatively hard Amuri limestone, Weka Pass stone, &c.

Means of Transport.

At Waipara the railway from Christchurch divides into two branches, one going north-west through Waikari, Medbury, &c., into Amuri County, and the other north-east through the Omihi Valley, Scargill, &c., into Cheviot County. The eastern settled part of the county is fairly well roaded. It has a sea-coast, but no port, unless the mouth of the Hurunui can be considered as such.

Literature.

The Waipara and adjoining districts have been examined by many geologists, and the energy expended in these visits and the subsequent reports and papers if economically directed would have easily supplied a detailed geological map and report on the eastern portion of the county at least. The principal references to the geology and structure of the county will be found in the following publications:—

Haast, Julius von: "The Geology of Canterbury and Westland," 1879. See geological map, and pp. 291–98, 304, 306–7, 316, 317–18, &c.

Rep. of Geol. Explor., No. 4, 1868, part of pp. 38–41; No. 6, 1871, pp. 5–19; No. 9, 1877, part of pp. 36–39; No. 13, 1881, pp. xxvi–xxvii, 108–18; No. 15, 1883, pp. xix–xx, 74–77, 78, 79; No. 18, 1887, pp. 78–91; No. 19, 1888, pp. xxxviii, 25–35; No. 21, 1892, pp. l–liii, 97–103, 147–48 (Ashley County).

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* See, however, analyses of limestone from Scargill, quoted above.

6th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1912, pp. 7–9; 7th Ann. Rep., part of Parl. Paper C.–2, 1913, p. 123; 9th Ann. Rep., part of Parl. Paper C.–2, 1915, pp. 90–93; 10th Ann. Rep., Parl. Paper C.–2B, 1916, pp. 16–17, 25–29.

Trans. N.Z. Inst., vol. 6, 1874, part of pp. 297–309; vol. 14, 1882, pp. 410–14; vol. 20, 1888, pp. 257–63; vol. 37, 1905, pp. 535–46; vol. 39, 1907, pp. 475–76; vol. 43, 1911, pp. 384–89, &c.; vol. 44, 1912, pp. 221–33; vol. 47, 1915, part of pp. 347–49; vol. 48, 1916, part of pp. 48–58; vol. 50, 1918, part of pp. 65–93 (Speight and Wild).

Quart. Jour. Geol. Soc., vol. 41, 1885, pp. 204 *et seq.*, 266–78 (Hutton).

15. Westland County.

Westland County is a narrow strip of country nearly 200 miles in length, extending along the western side of the Southern Alps from the Taramakau River to Big Bay. By the addition of part of Grey County it would become coterminous with the old provincial district of Westland. Near the water-parting the mountains consist of greywackes and argillites, probably of old Mesozoic age, in part possibly older. Westward these rocks become more and more schistose, until at last they pass into phyllites and schists, which are older than the rocks to the east, but how much older is not known. In North Westland a belt of gneiss and granite forms the western margin of the mountains, but these rocks are little developed south of the Big Wanganui River. Great reversed faults form the true western boundary of the Alps. In various districts a foothill country composed of greywacke and argillite, in places intruded by granite, makes its appearance. In the Hokitika, Ross, Paringa River, Arnott Range, and Jackson's Bay districts Tertiary conglomerates, sandstones, limestones, and claystones of Eocene and Miocene age may be seen, but are more or less smothered by fluviatile and glacial gravels of Pleistocene and Recent age. These gravels are in fact the characteristic rocks of the Westland lowlands. At Koiterangi Hill, or Camelback, an isolated hill 1,841 ft. high, about twelve miles south of Hokitika, limestone covers an area of some hundreds of acres, extending from the summit eastwards to the plain at the foot of the hill, where the height above sea-level is about 150 ft. The strike is a little to the east of north, and the dip to the south of east at angles of 10° to 25°. The maximum thickness is about 250 ft., but the lower part is a calcareous sandstone rather than limestone. At the trig. station (1,841 ft.) on top of the hill the limestone is white, somewhat soft, and of fairly good quality, while near the old lime-kiln at the foot of the hill it is a hard tough bluish-grey rock of somewhat low grade. On the south-east side of the hill the limestone is again lighter-coloured and of somewhat better quality than at the lime-kiln. Analyses of Koiterangi limestone are tolerably numerous, as will be seen from the tables below:—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Calcium carbonate	81·04	79·90	84·47	94·88	87·38	84·54	83·75
Magnesium carbonate				..	..	..	..
Siliceous matter, &c.	18·62	19·64	15·02	..	..	..	..
Water	0·34	0·46	0·51	..	..	..	..
	100·00	100·00	100·00	..	..	..	..

References.—(1) to (3) From Koiterangi, forwarded by Mr. A. Barron, of Lands and Survey Department. Col. Lab. 34th Ann. Rep., 1901, pp. 12–13. Lab. Nos. 8873/1–3.

(4) to (7) From Mount Camelback (Koiterangi Hill), forwarded by Mr. John Peake, jun., per Hon. Minister of Mines. Dom. Lab. 41st Ann. Rep., 1908, p. 18. Lab. Nos. 1070/1–4.

	(8)	(9)	(10)	(11)
Silica (SiO_2)	24·0	6·35	20·91	16·29
Alumina (Al_2O_3)	3·5	1·70	4·29	2·80
Iron oxides (FeO and Fe_2O_3)	1·8			
Titanium oxide (TiO_2)	0·1	..	..	..
Lime (CaO)	39·4	50·10	40·10	44·27
Magnesia (MgO)	1·2	1·19	1·89	1·59
Carbonic anhydride (CO_2)	30·0	39·40	32·81	35·05
Organic matter, water, and undetermined	..	1·26		
	100·0	100·00	100·00	100·00
Calcium carbonate ($CaCO_3$) equivalent to lime (per cent.)	70·36	89·46	71·61	79·05

References.—(8) From quarry near lime-kiln, Koiterangi Hill. N.Z. Geol. Surv. Bull. No. 1, 1906, p. 80. Lab. No. 421/1.

(9) Probably from near top of Koiterangi Hill; collected by P. G. Morgan in 1906 or 1907. N.Z. Geol. Surv. Bull. No. 6, 1908, p. 150; and Dom. Lab. 41st Ann. Rep., 1908, p. 22. Lab. No. 1442/1.

(10) (11) From south-east base of Koiterangi Hill, near road; collected by P. G. Morgan in November, 1906. Same references as No. 9, but pp. 20–21 of Dom. Lab. Rep. Lab. Nos. 1397/1–2.

Owing to the loss of a list of specimens collected, with details of locality, &c., the exact position of the points where the samples represented by analyses Nos. 9 to 11 were collected cannot now be quite definitely stated.

The following two analyses of lime made from Koiterangi limestone may be given :—

	(1)	(2)
Silica	..	25·2
Matter insoluble in acid	25·66	..
Alumina	6·13	5·0
Iron oxides		2·0
Titanium oxide	..	0·2
Lime (CaO)	50·14	45·4
Magnesia (MgO)	1·12	1·3
Carbonic anhydride	8·45	10·8
Water of hydration	8·50	10·1
	100·00	100·0

References.—(1) " Burned lime " from Koiterangi. Same reference as limestone-analyses Nos. 1 to 3 above. Lab. No. 8873/4.

(2) From Koiterangi lime-kiln (McArthur's). Same reference as limestone-analysis No. 8 above. Lab. No. 421/2.

The following analyses of limestone from Hokitika probably represent Koiterangi Hill samples :—

	(1)	(2)	(3)
Matter insoluble in acid	11·20	33·40	5·43
Alumina and iron oxides	3·95	5·05	2·02
Calcium carbonate	81·20	58·26	92·55
Magnesium carbonate, &c.	3·65	3·29	..
	100·00	100·00	100·00
Quicklime (CaO) in calcined stone (per cent.)	75	45	88

References.—(1) (2) From Hokitika, forwarded by Rabbit Inspector. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. Nos. D 600/1, 2.

(3) Same locality and sender as Nos. 1 and 2. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. No. E 236.

The analyses quoted show that, as already remarked, the Koiterangi limestone is very variable in quality. It is unfortunate that a quarry was established at a point where the stone is highly arenaceous, whereas not very far to the south better stone is found in almost or quite as convenient a position. The best stone, however, appears to be on top of the hill, nearly 1,700 ft. above the Kokatahi-Koiterangi Plain, and therefore in a position where its use seems out of the question. It is to be regretted that the exact locality of several of the samples analysed is not known. Some further sampling of the Koiterangi limestone is therefore desirable. In view of its uneven quality, the pulverization rather than the calcination of the stone is to be recommended.

The Koiterangi limestone is now known to be of Eocene age, and equivalent to the "island sandstone" near Greymouth, which immediately overlies the coal-measures and is in places, especially north of Dunollie, highly calcareous (see p. 212). It was supposed by McKay to be the equivalent of the Cobden limestone, and this view was quoted and tentatively adopted by the writers of bulletins Nos. 1 and 6. The detailed geological survey of the Greymouth district has thrown light on the correct stratigraphical relations. (See N.Z. Geol. Surv. Bull. No. 13, 1911).

Nearly white but apparently not high-grade limestone outcrops on the Koiterangi Plain less than half a mile north of Koiterangi Post-office, and rather more than a mile north-north-east of McArthur's lime-kiln. The outcrops form a low ridge on Mr. Cropp's farm. They are close to the main road, and therefore in a very accessible position. The stone ought to be sampled. Its position indicates that it is to be correlated with the Koiterangi Hill limestone, but it has the appearance of the Cobden limestone.

On either side of the Mikonui River valley, north-east and south-east of Gribben Flat, are small areas of Miocene strata. These are seen in the headwaters of the Totara River, and in Pothole and Slate creeks, tributaries of the Mikonui. The Miocene rocks include some highly calcareous grit, conglomerate, and claystone, and in Smyth Creek (tributary of Totara) there is a band that might be called arenaceous limestone. A sample of grey calcareous mudstone or claystone from Slate Creek had the following composition: Silica, 46·13; alumina, 15·25; iron oxide, 1·80; lime, 16·95; magnesia, 1·91; carbonic anhydride, 11·20; water, 2·81; alkalies and undetermined, 3·95. Lab. No. 1441; date of analysis, 1907.

The localities just mentioned are about nine miles inland, and somewhat difficult of access. Their calcareous rocks are of no value to the coastal belt, but may possibly be utilized some day for the Upper Totara and Mikonui river-flats.

In the latter part of 1905 an outcrop of high-grade limestone was discovered by Mr. H. Hamilton, Field Assistant, Geological Survey, at the head of Hodson Brook, a small tributary of Donnelly Creek, near Ross. The locality is a little over a mile due east of Ross, and somewhat under 60 chains south of the point where Hodson Brook crosses the Main South Road. During the past few years this limestone has received a good deal of attention. A company to work the deposit has been formed, and a lime-kiln, now in active operation, has been built.

The following statements are extracted from a report by Mr. A. McTaggart, of the Agricultural Department, dated 19th July, 1917:—

Near Ross excellent stone of high grade was, after persistent explorations in densely wooded country, finally found in satisfactory quantities. On cutting a track up Hodson Creek an escarpment of rubbly hard limestone was found, which proved to be a continuation of the ridge running north-west toward Ross Township, and connecting Hodson and Coal creeks. From this ridge Mr. McTaggart and party had taken samples on an earlier occasion. The Hodson Creek outcrop is approximately 60 chains from the Ross–Hokitika Road, and is estimated to be 450 ft. above sea-level. The quantity of stone exposed is some thousands of tons, and, on account of its loose rubbly nature, it can easily be quarried. At Mr. McTaggart's request Mr. C. S. Dalgleish, Fields Inspector, Hokitika, searched Coal Creek valley for a supposed outcrop of limestone, but found none in place. He reported, however, that on the spur or ridge west of Hodson Brook facing Ross there was a fair amount of limestone at a spot only 10 or 12 chains from Donnelly Creek. Mr. Dalgleish was of opinion that suitable sites for lime-works could be found immediately below the trig. station on the ridge, where there was a 100 ft. face of limestone, or at Connelly's Creek, near Donnelly Creek. He thought that 300,000 tons of limestone was available at either site.

Mr. McTaggart quotes the following analyses by Mr. B. C. Aston :—

Lab. No.	Sample No.	Calcium Carbonate, per Cent.
J 143	1	84·8
J 144	2	94·6
J 145	3	87·4
J 146	4	96·1
J 147	5	94·0
J 148	6 (near Donnelly Creek)	95·3
J 149	7 ,,	96·0
J 150	8 ,,	93·0

A sample from Hodson Creek (at the end of the ridge) yielded 90·6 per cent. This was obtained near the spot where limestone was discovered by Mr. Hamilton in 1906. A sample taken by him had the following composition :—

Silica (SiO_2)	5·45
Iron oxides and alumina (Fe_2O_3 and Al_2O_3)	1·17
Lime (CaO)	51·40
Magnesia (MgO)	0·81
Carbonic anhydride (CO_2)	39·80
Organic matter, water, and undetermined	1·37
	100·00

References.—N.Z. Geol. Surv. Bull. No. 6, 1908, p. 150 ; and Dom. Lab. 41st Ann. Rep., 1908, p. 22. Lab. No. 1442/2. The calcium carbonate equivalent to the lime present is 91·8 per cent., but other methods of calculation would give a lower result, and apparently the samples taken in 1905 and in 1917 agree very closely in composition.

Mr. H. Dickson, Resident Engineer, Public Works Department, Greymouth, visited the Hodson Creek outcrop and supplied a report on the cost of transport. His report, which was dated 8th May, 1917, dealt with other localities as well. The part relating to Hodson Creek may be summarized as follows :—

Hodson Creek : Total length from road, say, 60 chains ; approximate height above road, 450 ft. Limestone may be sent in a shoot to the creek immediately under the face, and then trammed on a fairly easy grade to a suitable kiln-site on the open ground, or may be trammed on the top of the terrace to immediately above the kiln and there dropped into a shoot and hopper. The final scheme to be adopted would depend on better examination, but in any case the first cost would not vary very much. The alternatives are an incline (rope) tramway down the terrace, or a horse tramway along the foot of the terrace.

If the route on top of the terrace is adopted, the tram, road, shoots, three trucks, wire rope, and brake gear would cost about £1,000. The cost of getting limestone to the kiln could be taken at 1s. per ton. The cost of carting lime to Ross Railway-station, with coal as back loading, would be about 5s. per ton. A timber tram to connect the kiln with an existing tram to Papakamai Railway-station could be made for about £200. This might effect a net saving of 1s. per ton on the carting, thus reducing cost of transport to the railway from 5s. to 4s. per ton.

If the limestone were quarried and burnt at the same cost as at Cape Foulwind, Mr. McTaggart estimated that it could be placed on trucks at Ross for £1 2s. 6d. per ton, but he allowed only 4s. per ton for transport, instead of 6s. per ton as estimated by Mr. Dickson in the report quoted above.* Moreover, the estimate of cost at Cape Foulwind quoted by Mr. McTaggart apparently omitted several material items—namely, depreciation, repairs, and interest on capital. It is therefore safe to say that on the Cape Foulwind basis the lime delivered on trucks at Ross would cost about £1 10s. per ton.† This cost, however, could easily be reduced by several shillings per ton, and the employment of a rock-breaker would effect a further reduction in cost. Finally, by working on a large scale, the cost of lime on trucks could be reduced possibly to £1 per ton.

For data regarding costs at Cape Foulwind see page 190. The Cape Foulwind kiln cost approximately £523 16s. A similar kiln lined inside with firebrick set in fireclay would have cost approximately £625.

The Hodson Creek limestone strikes south-west towards Coal Creek, or perhaps west-south-west towards Donnelly Creek below the mouth of Coal Creek. The dip, by analogy with neighbouring outcrops, is at high angles, probably to the north-west. The limestone is involved in faults, and the information to hand does not enable any estimate of the quantity available for quarrying to be made. In Bulletin No. 6, page 103, the Hodson Creek limestone was doubtfully correlated with the Koiterangi limestone, whereas it is certainly the equivalent of the Cobden limestone, which, however, until a few years ago was also correlated with the Koiterangi limestone. The Cobden stone is now known to be of Miocene age, and far above the horizon of the Koiterangi limestone. The error was recognized when the detailed geological survey was extended to the Greymouth district (see Bull. No. 13, 1911, p. 53). In the colouring of the geological map of Totara Survey District (Bull. No. 6) the limestone area at the head of Hodson Brook was extended beyond the small cross at 420 ft., which really indicates a greywacke outcrop. The map requires correction by colouring the extreme western part of the supposed Eocene area (blue ruling) brown, and giving the remainder a diagonal green ruling (Greenland Series). The section CD requires a corresponding correction. Had a perfectly correct geological map been available it would probably have lessened the amount of search made by Messrs. McTaggart, Dalgleish, and others. The chief obstacle to that search, however, was the dense bush, which for some time seems to have prevented the explorers from locating the outcrop originally discovered by the Geological Survey party in 1906.

The Hodson Creek limestone is a nearly white close-grained rock. Under the microscope it is seen to be composed largely of calcite crystals, together with remains of Foraminifera, Polyzoa, and other organisms. A few grains of quartz and feldspar with some cloudy matter complete the section examined.

In October, 1918, some months after all that precedes had been written, one of the writers visited the Ross lime-works owned by the Westland Farmers' Co-operative Lime-producing Company. These consist of a kiln, various buildings, and an incline tram, at the top of which is the quarry. The kiln, which is on the eastern side of Donnelly Creek, is 32 ft. deep, with a diameter of 9 ft. at the top and a maximum diameter of 10 ft. 3 in. It discharges into four hoppers, and the total depth from its top to the floor of the drive below the hoppers is 40 ft. The rated capacity is 10 tons per day. The quarry is a considerable height above the kiln on the north side of the ridge between Coal Creek and Hodson Brook. The limestone being quarried is much shattered, and dips almost vertically: hence it is obviously involved in a strong fault. A short distance to the south-east, however, near the surveyor's station on top of the ridge, the limestone is less shattered. In the rock as quarried is a large amount of rubble, which has to be rejected from the kiln, but would be very suitable for pulverization and use as a soil-dressing without previous calcination. So far as can be judged by appearances the limestone is at least 140 ft. thick. It is yellowish-white in colour; and fossils, chiefly species of *Pecten*, are not uncommon. Limestone extends westward from Hodson Brook towards Donnelly Creek, and is found in Hood Creek, a tributary of Coal Creek, but does not reach the latter stream. Although, as stated above, no estimate of quantity can be made, yet there must be millions of tons, all apparently of good quality. As a supplement to the kiln now at work the erection of pulverizing machinery to deal with the limestone fragments that are too small for the kiln is clearly advisable. As a matter of fact, at the time of writing, steps in that direction are being taken by the Westland Farmers' Co-operative Lime-producing Company. A considerable amount of information regarding the company's operations will be found in the *Hokitika Guardian* of the 12th June, 1919, and in the *Greymouth Evening Star* of the same date.

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* Mr. Dickson had previously roughly estimated the cost of transport from the proposed quarry-site on the spur facing Ross at 4s. per ton, and this figure was adopted by Mr. McTaggart.

† According to figures published in the *Hokitika Guardian* of the 12th June, 1919, the first 200 tons of lime made cost £1 11s. 9d. per ton to produce.

In an early report (1877, p. 84) Cox states that the Miocene marls (Blue Bottom) at Ross are interstratified in their upper layers with shell limestone. No shelly rock, other than small masses of shelly and partly concretionary calcareous claystone, was observed in the course of the detailed geological survey made during 1905 and later years.

South of Ross no limestone* is known to exist in Westland until the mouth of the Paringa River, about eighty-five miles south-west of Ross as the crow flies, is reached. According to Cox (1877 report, p. 82) a band of limestone traversed in all directions by veins of calc-spar (calcite) occurs here, resting on volcanic rocks, and overlain by marl, coarse sandstone, and conglomerate. From this locality it may be traced south-westward to the neighbourhood of the Abbey Rocks, where Messrs. Arthur and Docherty in January, 1876, were opening a quarry in a band of blue limestone with a view to ascertaining its value as a lithographic stone. The strata at this place had a dip of 45° to the north-west. Above this limestone Cox observed black shales, green sands, and grey sandstone, followed by marls and shales. Towards the top of the hill above the quarry just mentioned a second limestone band occurred. The lower beds were coarse, but the upper beds were fine-grained, and apparently suitable for use as a lithographic stone. The uppermost layer of limestone was coarser-grained, and capped by a fine-grained sandstone, which formed the summit of the hill. The limestone could be traced for some distance to the southward, where it was well exposed along the sea face. Its thickness was at least 150 ft. The dip was to the north-east at an angle of 15°. (Cox, 1877 report, pp. 81–82.)

South of the Abbey Rocks limestone occurs on the sea-coast, at one point having an east-and-west strike with a northerly dip of 50°, but a little to the south the strike veers to the north-east. It is underlain by marls and greensands.

Cox's remarks on the quality of the lithographic limestone near Abbey Rocks will be found on page 87 of his report (1877).

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* After this was written the writers learnt that a deposit of calcareous sinter had been discovered near Harihari, south of the Big Wanganui River. A sample which has been analysed contained 95 per cent. of calcium carbonate. (Aston, B. C., in Jour. Agric., vol. 17, No. 2, Aug., 1918, p. 99.)

The following analyses may be quoted:—

	(a)	(b)	(c)
Carbonate of lime	87·87	70·73	85·69
Carbonate of magnesia	3·12	3·14	5·78
Iron oxides with alumina	1·71	4·18	1·57
Clayey matters	5·39	20·45	4·94
Water	1·91	1·50	2·02
	100·00	100·00	100·00

Reference. — Fine-grained homogeneous limestones from Westland, forwarded by Mr. William Docherty to be tested for suitability for use as lithographic stones. Col. Mus. and Lab. 10th Ann. Rep., 1875, p. 15. Lab. Nos. 1711/*a*, *b*, *c*. These samples were no doubt from the vicinity of the Abbey Rocks.

Many years ago the late Mr. Charles Douglas, the well-known Westland explorer, reported the existence of coal and limestone outcrops in the Arnott Range, some distance south of Arnott Point. The limestone areas are shown in a map published in the Mines Report, Parl. Paper C.–3, 1890, opposite page 96. They occur near the base of Bald Hill in the valleys of Wells and Kiwi creeks, tributaries of Bullock Creek, some miles from the coast. Von Haast's geological map of 1879 shows a strip of "Cretaceo-Tertiary" rocks extending from the north side of the Paringa River to this locality.

In the headland on the western side of Jackson's Bay limestone, much faulted and folded, occurs. This extends for some distance to the south. In Saddle Creek, a tributary of Smoothwater Creek, is a band of limestone about 10 ft. thick and interstratified with marls. These particulars are based on the account of the Jackson's Bay limestone and associated beds given by Cox (1877 report, pp. 94–95). His report, however, cannot be easily understood without the aid of a map. Analyses of limestone from Jackson's Bay are as follow:—

	(1)	(2)
Carbonate of lime	87·1	74·7
Oxide of iron	..	6·6
Insoluble matter	..	19·7
	..	101·0

Reference.—(1) Fine-grained limestone, and (2) coarse sandy limestone, forwarded by Mr. D. Macfarlane. Col. Mus. and Lab. 14th Ann. Rep., 1879, p. 25. Lab. Nos. 2337/1, 2.

The name "Limestone-cliff Bay," applied to an inlet near Gorge River, seems to indicate the occurrence of limestone at that place.* Park describes a small area of fault-involved "Cretaceo-Tertiary" rocks, consisting in part of limestone, which occurs at Awarua Point, the north headland of Big or Awarua Bay (1887 report, p. 131). Similar beds are seen at the south headland, which, however, is in Lake County. Von Haast's geological map of 1879 shows a strip of "Cretaceo-Tertiary" rocks (maximum width six miles) extending uninterruptedly from Jackson's Bay to Big Bay, except north east of Barn Bay, where Quaternary alluvium hides the older rocks. The correctness of this mapping may be doubted.

Summary of Limestone Resources, &c.

In proportion to its size Westland is not well off for limestone deposits. The Koiterangi limestone, though of moderate quality only, is excellently situated to supply the needs of the Kokatahi-Koiterangi Plain. The Ross limestone is of high quality, and, if the quantity is sufficiently great to justify the erection of large lime-works, will be of great value to the area served by the Reefton–Greymouth–Ross Railway and any future southward extension. This was anticipated in 1908 when the writer of Bulletin No. 6 remarked (p. 149) that the Hodson Creek limestone would probably be found of considerable value in the future (for agricultural purposes). The use of limestone for the manufacture of nitrate of lime with the aid of nitric acid made from the air by an electrical process was also suggested (p. 150). Abundant water-power is available.

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* On the north side of the mouth of the Gorge River there is a limestone bluff over 50 ft. high. In the limestone are some caves, one of which is used as a camping-place by the few travellers that visit the locality. The limestone appears to be somewhat arenaceous, but is otherwise of good quality. Its bedding is nearly horizontal. (M. Ongley.)

At present no convenient source of lime can be suggested for the numerous river-flats south of Ross. The extension of the railway to the Waitaha River will bring the Waitaha Settlement within easy carting distance of the railway, but there is little present likelihood of the railway reaching the Big Wanganui and Wataroa districts, where also there is much agricultural land. Some portions of South Westland may perhaps obtain lime from the deposits at Paringa River, Abbey Rocks, Arnott Range, Jackson's Bay, &c. Those at Paringa River, Abbey Rocks, and Jackson's Bay are near the sea, and the material could perhaps be shipped along the coast. This, however, may be considered quite impracticable at the present time.

Means of Transport.

Westland as a whole is somewhat badly provided with means of communication. From Greymouth a railway, entering the county at the Taramakau River, runs southward—or, rather, south-westward—to Ross. The settled portions of the county north of Ross are well roaded, and there are also many sawmill-trams. South of Ross there is a main road to Okarito Forks, whence branches diverge to the neighbourhood of the Franz Josef Glacier and Okarito. From this main road a few short branch roads, most of which are well gravelled, have been made to open up the agricultural land. In 1908 south of the Waiho River there were practically no roads of any consequence other than bridle-tracks. The writers have not ascertained the progress made in road-construction during the past ten years, but it is not great. The Big Wanganui and Wataroa rivers, however, have been bridged, the latter in 1908, the former some years later. Notwithstanding its two hundred miles of coast-line, Westland County has no good harbour. The mouths of nearly all the larger rivers can be entered by small craft. The most used of these river-ports is Hokitika. The Okarito Lagoon forms a fair harbour, but at times the entrance is closed. Other points where produce is shipped are Bruce Bay and Okuru. Jackson's Bay is well sheltered from the southerly winds but open to the stormy north-westerly. Cascade River is said to have deep water inside the bar. Von Haast considers that a harbour could be made at the mouth of the Paringa River. Barn Bay affords shelter from all winds except the westerly.

Literature.

Nearly the whole of North Westland as far south as the Big Wanganui River has been geologically surveyed in detail. The results are comprised in N.Z. Geol. Surv. Bull. No. 1, 1906, "The Geology of the Hokitika Sheet, North Westland Quadrangle," by J. M. Bell and Colin Fraser; Bull. No. 6, 1908, "The Geology of the Mikonui Subdivision, North Westland," by P. G. Morgan; and Bull. No. 13, 1911, "The Geology of the Greymouth Subdivision, North Westland," by P. G. Morgan. The lists of literature contained in these publications include nearly all the papers and reports that deal with the geology of Westland County. The publications referred to on the preceding pages are von Haast's "Geology of Canterbury and Westland," 1879, and Cox's reports of 1877 in Rep. of Geol. Explor. No. 9, 1877, pp. 63–93 (Westland District) and 94–95 (Jackson's Bay). Reference was also made to a map by Charles Douglas in Mines Report, Parl. Paper C.-3, 1890, opposite p. 96. This is accompanied by another geological map and sections, also by Douglas, together with a brief account of some of his explorations (pp. 96–97). Fuller particulars of Douglas's work will be found in some of the annual reports of the Lands and Survey Department for the years during which he conducted his explorations. Other accounts of explorations in South Westland will be found in these reports and in other publications, but, being mainly topographical, need not be mentioned here. An exception may be made in favour of "A Geographical Report on the Franz Josef Glacier," 1910, by J. M. Bell and others (a publication of the N.Z. Geological Survey).

16. Tawera County.

Tawera County is a mountainous portion of north-west Canterbury extending from the Southern Alps to the inland edge of the Canterbury Plain. The chief rocks are greywackes and argillites of supposed Trias-Jura age. The reported presence of marble in the Mount White district raises the question whether Maitai or even older rocks are not present also. Small patches of Cretaceous and Tertiary conglomerates, sandstones, limestones, claystones, &c., occur sporadically through the county. These are all more or less fault-involved or fault-bounded, unless the coal-measure rocks near Springfield be regarded as an exception. Igneous dykes and volcanic tuffs occur in several localities. Morainic and fluviatile gravels form the youngest rocks of the county. The flat lands of Tawera County comprise several small intermontane basins, various gravel-floored valleys, and the agricultural land near Springfield which forms part of the Canterbury Plain.

McKay (1881 report, p. 88) states that "nests or lenticular patches of dark-grey compact limestone" are associated with the grits, sandstones, and shales occurring between the Cass and Bealey rivers. These cannot well have any economic importance, but may be of great geological significance.* The following analysis of a sample of white marble from "Mount White River" (? Esk River) possibly represents a patch or lens of limestone similar to those described by McKay:—

Carbonate of lime	97·63
Carbonate of magnesia	1·57
Alumina	0·19
Iron oxides	Trace
Silica (? matter insoluble in acid)	0·58
Water	0·03
	100·00

Reference.—Forwarded by Mr. J. D. Enys. Col. Mus. and Lab. 16th Ann. Rep., 1882, p. 30. Lab. No. 2852/2.

A most interesting patch of Cretaceous and Tertiary rocks occurs in the upper valley of the Broken River, in an intermontane fault-bounded depression known to geologists as the Trelissick Basin. According to Hutton two limestones are present, one Cretaceous and one Tertiary. The older, believed to represent the Amuri limestone, outcrops more or less continuously along the northern and south-eastern margins of the basin. It is somewhat argillaceous, and varies in thickness from 100 ft. to 300 ft. (Hutton, 1887, p. 400). The younger limestone, of Miocene age, is best exposed at Castle Hill near the West Coast Road, where it is not less than 100 ft. or, according to Speight, 150 ft. thick. The dip is westerly, at angles of 25° to 32°. At the junction of Thomas and Porter rivers the limestone is 50 ft. thick, and is underlain by volcanic

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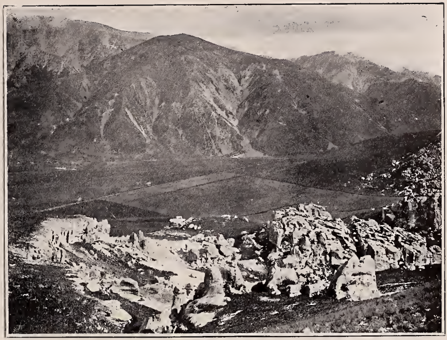
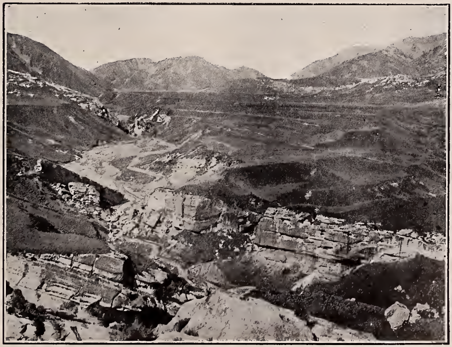
* McKay states that a fossil obtained from a block of the marble was probably the Dun Mountain "*Inoceramus*"—i.e., *Aphanaia* sp. (See also Awatere, Waimate, and Waitaki counties.)



A. View of the Trelissick Basin, looking South-east from the Summit of Castle Hill.

The limestone in the foreground is dipping towards the observer.

[*From a paper by R. Speight in vol. 49, Trans. N.Z. Inst.*]



B. View of the Trelissick Basin, looking South-west from the Hill between Broken River and Porter River.

The limestone in the foreground forms here the lower gorge of the Porter River, but it appears again farther up-stream after making a swing round to the left, and is seen again in the distance forming the eastern face of Castle Hill.

[*From a paper by R. Speight in vol. 49, Trans. N.Z. Inst.*]

grit (10 ft.) and tufaceous greensands (40 ft.). These beds dip at 20° to 25° to the west. In Home Creek the limestone is 60 ft. to 70 ft. thick, and has a dip of 20° to the west-south-west (Hutton, 1887, pp. 401, 402). Speight considers that there is only one limestone, which in places is divided by volcanic tuff, &c. (1917, p. 336, &c.). He gives a very full and careful account of the stratigraphy and palæontology of the Trelissick Basin strata. In another paper he notes the presence of a great mass of Tertiary limestone in the valley of the Esk River near Mount White (1915, p. 344).

Summary of Limestone Resources and of Means of Transport.

The limestones of the Trelissick Basin are many miles by road from the railway, and at present can supply lime only to the small area of agricultural land in the basin itself. The Castle Hill limestone is a good building-stone (Speight, 1917, p. 332).

The Midland Railway line runs through the county from Springfield to Arthur's Pass. At the time of writing the headings of the great Otira Tunnel have almost met.* The completion of this tunnel will give Tawera County communication with the West Coast. For the present the Springfield and other agricultural districts will have to obtain their lime from Waipara County. The railway haulages are somewhat long, the distance from Waikari to Springfield via Rangiora, Oxford, and Sheffield being about sixty-nine miles, and to Cass, where there is some agricultural land, ninety-seven miles.

The Springfield district is well roaded, but farther west the only roads of any consequence are the old West Coast coach-road from Springfield via Porter's Pass, Castle Hill, &c., to Arthur's Pass, portions of which are now in rather a bad state, and the new road from Cass to Broken River, which runs close to the railway-line.

Literature.

Most of the geological literature relating to Tawera County has reference to the Trelissick Basin. The energy already expended on this area, if well directed, would have given a detailed geological map of a considerable tract of the surrounding country as well as of the basin itself, and would probably have settled some important geological problems. The chief publications dealing with Tawera County geology are—

Haast, Julius von: "Geology of Canterbury and Westland," 1879, pp. 108–9, 141–42, 145–52, 203, 391–92, &c.

Rep. of Geol. Explor., No. 6, 1871, p. 142 (coal near Springfield); No. 8, 1877, a small part of pp. 27–58; No. 13, 1881, pp. xx–xxvi, 53–74 (McKay, on Trelissick Basin), part of pp. 83–107; No. 16, 1884, pp. 19–22 (Cox); No. 17, 1886, pp. 20–21 (Lindop), 22–27 (Cox); No. 21, 1892, p. 15 (McKay, on faulting), part of pp. 162–63 (Selwyn County).

Trans. N.Z. Inst., vol. 19, 1887, pp. 392–412 (Hutton); vol. 37, 1905, pp. 534–35 (Park); vol. 41, 1909, p. 33 (Gudex, on striated stones); vol. 43, 1911, pp. 390, 392 (Marshall, Speight, and Cotton); vol. 47, 1915, pp. 341–45 (Speight); vol. 48, 1916, pp. 145–53 (Speight); vol. 49, 1917, pp. 321–56 (Speight). The last-mentioned paper is the most complete account of the Trelissick Basin to date. Unfortunately the sketch-map on page 323 is on too small a scale, and is not equal in detail to Hutton's map of 1888 (plate xxiv).

17. OXFORD COUNTY.

Oxford County is an inland area lying east of Tawera County. In the west the Puketeraki Range, formed of Trias-Jura (or possibly in part Permo-Carboniferous) rocks, forms the watershed between the Ashley River and the Esk. Similar rocks form most of the county to the east of the Puketeraki Range as far as Oxford Hill. The rest of the county is covered by the gravels of the Canterbury Plain, with the exception of a few patches where Cretaceous or Tertiary strata appear, and of several volcanic hills, such as Burnt Hill, &c.

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* The headings met on 20th July, 1918.

A low ridge eight miles (or less) westward of Oxford, and near the base of Oxford Hill (4,392 ft.), is partly composed of a chalky rock, generally supposed to represent the Amuri limestone, which is believed to be of Upper Cretaceous age. According to Mr. Henry Wilson, however, the chalk is of Oamaru age. It outcrops at the northern end of the ridge, which is cut through by a small branch of Eyre River. South-westward, on the banks of the Eyre, inferior chalky strata are overlain unconformably by vesicular volcanic rocks. McKay considers that the chalk dips to the south-east at angles of 25° to 30°, and that its total thickness is not less than 100 ft. (1881 report, p. 50). He is also of the opinion that it can be used for making lime, Portland cement, crayons, &c. The chalk, however, is somewhat siliceous or in places argillaceous, and variable in quality. It is therefore on the whole not suitable for the manufacture of lime, but probably can be easily and cheaply pulverized. Apparently the only drawback to its extensive use in Canterbury is its distance from the railway. Probably West Oxford is the nearest railway-station.

Analyses of the chalk are—

	(1)	(2)
Matter insoluble in acid	15·69	32·10
Alumina	..	0·92
Iron oxides	Traces	Traces
Calcium carbonate	82·26	66·82
Magnesium carbonate	1·84	
Water	0·21	0·16
	100·00	100·00

References.—(1) Forwarded by Mr. John Ingram. Col. Mus. and Lab. 15th Ann. Rep., 1880, p. 34. Lab. No. 2597.

(2) Forwarded by Mr. John Ingram. Col. Mus. and Lab. 16th Ann. Rep., 1882, pp. 27–28. Lab. No. 2819.

View Hill, some miles south or south-west of the chalk deposit described above, is partly composed of sedimentary strata, mapped by von Haast as "Cretaceous." In 1915 two samples from View Hill analysed by B. C. Aston were found to contain 67·80 and 84·05 per cent. of calcium carbonate respectively. (Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 331. Analyst's Nos. G 204 and 205.) The samples may have come from View Hill as stated, or quite possibly from some neighbouring locality, the name View Hill in that case being merely the name of the district.

There are various patches of Tertiary strata in Oxford County, but no information concerning any limestone associated with them has been obtained.

Summary of Limestone Resources and of Means of Transport.

The chalk west of Oxford will probably be of considerable value for agricultural purposes in the future. So far as can be ascertained it must be used in the pulverized condition. Its value for the manufacture of crayons is problematical—in fact, school "chalk" or crayons are nowadays prepared from talc or steatite.

The flat part of Oxford County is traversed by the Kaiapoi–Sheffield Railway, and has excellent roads. Naturally or artificially pulverized limestone can be obtained in abundance from Waipara County. The railway haulages will not be excessive.

Exploration and sampling of the limestone deposits of the county are decidedly advisable.

Literature.

The chief references to the geology of Oxford County are—

Haast, Julius von: "Geology of Canterbury and Westland," 1879. See geological map, and a few casual references to localities in or near Ashley County.

Rep. of Geol. Explor., No. 8, 1877, a small part of pp. 27–58; No. 13, 1881, pp. xviii–xix, 49–53 (McKay, on Oxford chalk), and a small part of pp. 83–107; No. 21, 1892, part of pp. 147–48 (Ashley County).

Trans. N.Z. Inst., vol. 20, 1888, pp. 274–76 (Henry Wilson, on Oxford chalk deposit).

18. ASHLEY COUNTY.

The geology of Ashley County is much the same as that of the adjoining Oxford County, but Cretaceous and Tertiary rocks are better developed, and limestone is more abundant. Amuri limestone is exposed at several points on the Okuku River, and probably also on the Garry River (a small tributary of the Ashley) between mounts Ashley and Thomas. Somewhat farther east is a broad belt of Tertiary strata which strikes south-west across the county, in continuation of that described under Waipara County as reaching Mount Brown (Kowai County). These rocks contain beds of limestone which are usually thin and rubbly (Mount Brown limestone), but in places are of considerable thickness. This is the case at the White Rock quarries near Loburn, which at one time were worked for building-stone.

B. C. Aston states that two limestones from White Rock contain 78·65 and 96·08 per cent. of calcium carbonate respectively. (Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 331. Analyst's numbers and date: G 206 and 207, 1915.)

The following analysis represents a sample from Mount Grey:—

Silica (SiO_2)	1·90
Alumina (Al_2O_3)	2·05
Iron oxides (Fe_2O_3)	2·25
Lime (CaO)	50·30
Magnesia (MgO)	0·91
Phosphoric anhydride (P_2O_5)	0·76
Carbonic anhydride (CO_2)	38·85
Moisture and loss	2·98
	100·00
Calcium carbonate ($CaCO_3$), per cent.	88·3

Reference.—Forwarded by Mr. H. McLachlan. Col. Lab. 40th Ann. Rep., 1907, pp. 15–16. Lab. No. 937.

The following analyses by J. G. Black are quoted from "Official Record of the N.Z. and South Seas Exhibition, Dunedin, 1889–90" (Wellington, 1891, pp. 368–71):—

	(1)	(2)
Water	0·9	1·1
Carbonate of lime	76·0	80·0
Carbonate of magnesia	0·4	1·2
Oxides of iron	0·7	0·8
Silica combined	6·4	5·0
Alumina and oxide of iron combined	3·0	
Lime combined as silicate	2·0	
Magnesia combined as silicate	0·8	
Alkalies combined as silicate	1·1	
Sand (fine quartz-sand)	9·0	11·5
	100·3	99·6
Specific gravity (calculated from weight of 6 in. cube)	1·70	1·45

References.—(1) Hard, fairly cemented limestone from White Rock, Ashley, exhibited by Wilson's Quarries. Analyst's No. 4.

(2) Limestone similar to No. 1 from Ashley, exhibited by Thomas Croft. Analyst's No. 11. The sum of the constituents as given in the report cited is 99·7.

The Triassic rocks of the Okuku River contain bands or lenses of limestone, in which the fossil *Monotis salinaria* is more or less abundant (McKay, 1881, p. 100).

Summary of Limestone Resources and of Means of Transport.

Ashley County apparently possesses considerable limestone deposits, but these are some distance from the railway. Systematic exploration and sampling are necessary in order to obtain fuller information. The railway from Christchurch to Waipara, &c., just enters the county at Ashley Station. The settled southern and eastern portions of the county are well roaded.

Literature.

There is not much literature concerning Ashley County as now constituted. The chief references, in addition to von Haast's "Geology of Canterbury and Westland," are the following:—

Rep. of Geol. Explor., No. 8, 1877, part of pp. 27–58; No. 10, 1877, part of pp. 44–46; No. 13, 1881, part of pp. 83–107; No. 21, 1892, part of pp. 147–48 (which refer to the old Ashley County, with much more extended boundaries than the present county).

19. KOWAI COUNTY.

In the western part of Kowai County old Mesozoic greywackes and argillites are well developed, together with considerable areas of Cretaceous and Tertiary rocks containing much limestone. The rest of the county forms part of the Canterbury Plain. The bands of Amuri limestone, Weka Pass stone, and Mount Brown limestone seen in the Mount Donald Range, Waipara County, extend southward into Kowai. The Amuri limestone, together with the overlying Weka Pass stone, reaches into the upper valley of Boby's Creek, where, owing to faulting and denudation, it ends. The faulting, however, causes another band to appear farther to the east, close to the Waipara River north of Mount Brown. This extends to the northern slopes of Mount Grey, where, owing to denudation (or, according to Speight and Wild, overlap [?] on older rocks), it disappears. The thickness of the Amuri limestone in this locality is only 25 ft. This suggests unconformity. The overlying Weka Pass stone here passes into a calcareous greensand (Speight and Wild, 1918). The rubbly Mount Brown limestones extend to the same locality, and there disappear for the same reason. From von Haast's geological map it appears probable that more limestone exists east and south of Mount Grey, but no information concerning this possible limestone has been obtained. No analyses of limestone from Kowai County have been found in the literature consulted.

Summary of Limestone Resources and of Means of Transport.

The western part of Kowai County apparently contains a good deal of limestone. This limestone, however, is at least seven or eight miles from the railway, and is known to be variable in quality. Exploration and sampling are necessary. The county is traversed by the Christchurch–Waipara Railway, and can easily obtain pulverized limestone from the adjoining Waipara County. Most parts of the county have good roads. There is no port on the sea-coast, which is therefore practically valueless as a means of communication.

Literature.

In addition to von Haast's "Geology of Canterbury and Westland," the following scattered references may be given:—

Rep. of Geol. Explor., No. 6, 1871, part of pp. 5–19; No. 8, 1877, part of pp. 27–58; No. 10, 1877, part of pp. 44–46, 52, 53, 59–63; No. 19, 1888, part of pp. 25–35; No. 21, 1892, parts of pp. 97–103, 147–48 (Ashley County).

Trans. N.Z. Inst., vol. 37, 1905, part of pp. 535–46 (Park); vol. 43, 1911, p. 384, &c. (Marshall, Speight, and Cotton); vol. 44, 1912, pp. 221–33 (Speight); vol. 50, 1918, part of pp. 76–77, &c. (R. Speight and L. J. Wild).

6th, 7th, and 10th Ann. Rep. N.Z. Geol. Surv., as mentioned under Waipara County (p. 224).

In general the literature dealing with Weka Pass, &c., is applicable to the north-west part of Kowai County.

20. RANGIORA COUNTY.

Rangiora County is almost wholly included in the Canterbury Plain. According to von Haast's geological map of Canterbury and Westland there is a small area of Tertiary beds in the western part of the county, south of the Ashley River. Probably these contain bands of calcareous rock, but no information has been obtained. The following analyses, ascribed to samples from Kaiapoi, probably represent material from this area or from one of the adjoining counties:—

	(1)	(2)	(3)
Matter insoluble in acid	21·78	17·82	23·78
Alumina and iron oxides	2·30	1·42	2·60
Calcium carbonate ($CaCO_3$)	74·00	80·70	72·94
Magnesium carbonate and undetermined ..	1·92	0·06	0·68
	100·00	100·00	100·00
Quicklime (CaO) in calcined stone (per cent.)	61	70	61

Reference.—Forwarded by R. Evans. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. Nos. E 807/1–3.

Rangiora County has good railway and road communications, and can conveniently obtain lime or pulverized limestone from other parts of North Canterbury—for example, the Waikari district.

Literature.

Direct references to Rangiora County in the geological literature are few in number. The chief publications dealing with the Canterbury Plain are cited on a later page.

21. EYRE COUNTY.

Eyre County is wholly included in the Canterbury Plain. Having good railway and road communications it can conveniently obtain pulverized limestone from Waipara, Oxford, or other counties in North Canterbury having limestone deposits.

22. MALVERN COUNTY.

The Malvern Hills, in the west of Malvern County, consist mainly of Trias-Jura rocks. Sedimentary and volcanic rocks of Cretaceous and perhaps in part of Tertiary age fringe the Malvern Hills on the north-east and south sides. The remainder of the county forms part of the Canterbury Plain. Limestone seems to be somewhat poorly developed. Von Haast (1872 report, p. 29) mentions an outcrop of argillaceous limestone in the rocks abutting against the Cairn Range. At a later date he states that there are several localities in the Malvern Hills—such as the Four Point Range on the right and Frank's Knob on the left bank of the Selwyn—where excellent limestones and marbles exist in considerable quantity (1879, pp. 463–64). The former locality, however, is outside the county as at present constituted.

Malvern County has good railway and road communications. It will probably have to obtain most of the lime it requires in the form of pulverized limestone from Waipara County or elsewhere in North Canterbury. Lime of good quality can be obtained from Ashburton County.

Literature.

Among the references to the geology of Malvern County, and more especially of the Malvern Hills, are—

Rep. of Geol. Explor., No. 6, 1871, part of pp. 46–55 (Hector), 135–46 (Haast); No. 7, 1872, part of pp. 1–88 (Haast); No. 15, 1883, part of pp. xvi. xvii, 57–62 (Cox); No. 16, 1884, part of pp. 22–43 and of map opposite p. 24; No. 17, 1886, part of pp. 15–21 (Lindop); No. 21, 1892, part of pp. 162–63 (Selwyn County).

Haast, Julius von: "Geology of Canterbury and Westland," 1879, pp. 16–18, 267, 283–85, 287, 293, 297, 452, 463–64, 466, &c. The Malvern Hills are mentioned on many other pages, but the references seem to be mainly to localities in Selwyn and Tawera counties.

See also Selwyn County literature.

23–30. PAPAROA, WAIMAIRI, HEATHCOTE, HALSWELL, SPRINGS, MOUNT HERBERT, AKAROA, AND WAIREWA COUNTIES.

Of these eight counties, Paparoa, Waimairi, and Springs are wholly included in the Canterbury Plain. The western portions of Heathcote and Halswell counties, and a small part of Wairewa County, are also contained in the Canterbury Plain. The other portions of these counties, together with Mount Herbert and Akaroa counties, form Banks Peninsula, which is a semi-mountainous area composed almost wholly of volcanic rocks. Small patches of ancient sediments are exposed south of the head of Lyttelton Harbour.*

The flat densely populated country west of Banks Peninsula contains the city of Christchurch, and has excellent railway and road communications. It can obtain its lime-supplies by rail from North Canterbury (Waipara County), or can import them by sea from Amuri Bluff (as was actually done many years ago) or Kaikoura. Ashburton County is another possible source of supply. A railway runs to Little River in Banks Peninsula, and can materially aid in the distribution of lime to Akaroa County. Banks Peninsula contains the fine harbours of Lyttelton (connected by rail with Christchurch) and Akaroa, as well as many other inlets that may be used as ports for small vessels. It therefore has good sea communications. The Akaroa district will probably find it most convenient to import the not very large quantities of lime needed by sea from Kaikoura or Amuri Bluff, in the form of lump or pulverized limestone.

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* These are described more fully by Speight than by other writers. See his paper of 1917.

Literature.

The literature having reference to the eight counties mentioned above deals either with artesian water-supplies, the Canterbury Plain, or Banks Peninsula. The Canterbury Plain literature is cited under Ashburton County. The chief publications dealing with the geology of Banks Peninsula are—

Haast, Julius von: "Geology of Canterbury and Westland," 1879, pp. 62–63, 157, 261, 265, 324–65, 367, 369, 413 *et seq.*

Rep. of Geol. Explor., No. 8, 1877, p. 33 (at bottom); No. 21, 1892, p. 146.

Trans. N.Z. Inst., vol. 7, 1875, pp. 54–91, 98–105; vol. 11, 1879, pp. 495–512 (von Haast); vol. 15, 1883, pp. 411–14 (Hutton); vol. 22, 1890, pp. 64–70 (John Meeson); vol. 23, 1891, pp. 373–75 (H. O. Forbes); vol. 25, 1893, pp. 367–75 (Speight); vol. 26, 1894, pp. 368–87 (Marshall), 408–14 (Speight); vol. 40, 1908, pp. 176–84 (Speight); vol. 49, 1917, pp. 365–94 (Speight). The last-cited paper gives a complete account of the topography and geological history of Banks Peninsula. A paper on the petrology is promised later.

Some of the papers having reference to artesian wells are—

Trans. N.Z. Inst., vol. 28, 1894, pp. 654–64 (Hutton); vol. 43, 1911, pp. 420–36 (Speight); vol. 44, 1912, pp. 142–49 (F. W. Hilgendorf). See also von Haast, 1879, pp. 468–73.

31. SELWYN COUNTY.

Selwyn is a fairly large county, extending south-east from the Southern Alps to the main railway-line south of Christchurch. The Rakaia River forms the southern boundary, and drains most of the mountainous western portion. The eastern portion is part of the Canterbury Plain.

The geology of Selwyn County is similar to that of Tawera and Malvern counties, which adjoin it on the north. Tertiary rocks are somewhat better developed than in the last-named counties.

Bands of hard crystalline limestone, interbedded with old Mesozoic jasperoid argillite and diabasic ash, occur between the foot of High Peak and the Selwyn Gorge (Cox, 1884 report, pp. 27, 28, 29). Samples which probably came from near the road between Whitecliffs and the upper Selwyn Valley had the following composition:—

	(1*a*)	(1*b*)	(2)
Carbonate of lime	96·42	96·44	98·53
Carbonate of magnesia	2·79	2·79	..
Alumina	0·58	0·56	Present
Iron oxide	Trace	..	..
Manganese oxide	..	..	Present
Silica (? matter insoluble in acid).. ..	0·21	..	Present
Water	..	0·21	..
	100·00	100·00	..

The first two analytical statements refer to the same sample, but one or the other is misquoted, probably (*b*). (See references below.)

References. — (1*a*) Forwarded by Mr. H. A. Ogdon (? Ogden). Col. Mus. and Lab. 20th Ann. Rep., 1886, p. 41. Lab. No. 4032.

(1*b*) Forwarded by Messrs. Ford and Ogden on 15th June, 1885 (Lab. No. 4032). Rep. of Geol. Explor., No. 19, 1888, p. xxx.

(2) Blair, W. N.: "The Building Materials of Otago and South New Zealand generally," Dunedin, 1879, p. 29. Analysis by Professor A. W. Bickerton.

B. C. Aston in Jour. Agric., vol. 17, No. 2, Aug., 1918, p. 100, gives an analysis of an impure limestone from "Whitecliffs," with 67·30 per cent. of calcium carbonate. The sample analysed may have come from the Mesozoic rocks of the Malvern Hills.

The Lands and Survey Department's map of Hororata Survey District shows a marble-quarry on High Peaks Road at a point not quite two miles east-north-east of High Peak trig. station. This quarry has not been worked, so far as the writers can ascertain, at any time within the last thirty years. The locality seems to be that mentioned by Cox (1884) and also by Hector (1888, p. xxx). In the publication cited above Blair states (pp. 28–30) that marble-quarries had been opened in a conical hill eight miles from Whitecliffs Railway-station by an influential company formed in 1876. Two varieties of marble were being quarried: one (the "grey") was of a general grey colour, due to a bluish-black ground with distinct white lines, and the other (the "imperial red") was of a mottled light-red colour. Blair says also that the deposit was practically inexhaustible — a statement that, one may fear, is not wholly correct.

In April, 1919—that is, some time after the manuscript of this report had been forwarded to the printer—the quarry mentioned above was visited by one of the writers (P. G. Morgan). He had little time for inspection, and saw nothing to justify a hopeful view of the marble, either as a source of lime or as an ornamental stone. It occurs as an almost vertical irregular band, only a few feet thick, and probably of no great length. The stone seen by Mr. Morgan was hard and fine-grained, and its colour, on the weathered surface, was bluish-grey. Most of it appeared to be somewhat impure. A piece of reddish marble was found on the road below the quarry, but none was seen *in situ*. Some miles eastward of the old marble-quarry, bluish-grey fine-grained marble occurs on the mountain-side north-west of Mr. George Starkey's homestead. Mr. Starkey states that in this locality blocks of marble cover an acre or more.

A small outcrop of highly fossiliferous Middle Tertiary strata forms the lower portion of a terrace cliff on the left or north bank of the Rakaia River about five miles below Rakaia Gorge. The locality is known as the "Curiosity Shop." McKay (1881 report, p. 77) states that a thick bed of calcareous sandstone is exposed, and that calcareous sands 10 ft. to 12 ft. thick occur a little higher in the section.

Towards the head of the Harper River, a tributary of the Wilberforce, a small Tertiary outlier, consisting of sandy clays with impure lignite, greensands, concretionary sands, and concretionary shell-beds, has lately been discovered by Speight (1917, pp. 356–60). No information concerning the Tertiary outliers in the lower Harper and Wilberforce valleys (Speight, 1917, p. 360) has been obtained. The Cretaceous rocks at Rakaia Gorge do not include any calcareous layers, but at Oyster Hill, south-west of Glentunnel, and elsewhere is a well-known oyster-bed of Cretaceous age.

Summary of Limestone Resources and of Means of Transport.

Selwyn County appears to have very little limestone, and therefore must look to other parts of Canterbury for most of its lime. The Christchurch–Dunedin Railway, as already mentioned, forms its eastern boundary. A railway also reaches Whitecliffs, on the northern boundary. The flat settled eastern portion is well roaded. There are several roads in the Malvern Hills district, and a good road which reaches the Lake Coleridge district continues up the Wilberforce Valley almost to Browning's Pass, but the last portion has been out of repair for many years. A branch goes up the Rakaia for some distance, and may ultimately be continued over Whitcombe Pass into Westland, but much water will flow down the Rakaia River before such a road is made.

Literature.

The chief references to the geology of Selwyn County are included in the publications cited under Malvern County and the following:—

Rep. of Geol. Explor., No. 8, 1877, a small part of pp. 27–58; No. 13, 1881, pp. xvi–xvii, 75–82; No. 16, 1884, pp. 16–19, &c.; No. 17, 1886, pp. xi–xii, 6–8, 13–19; No. 18, 1887, pp. xiv–xv, 230–33; No. 19, 1888, p. xxx; No. 21, 1892, part of pp. 162–63.

"Geology of Canterbury and Westland," pp. 123–41, &c. (see Malvern County).

Trans. N.Z. Inst., vol. 20, 1888, pp. 271–74 (Hutton); vol. 45, 1913, pp. 331–35 (Speight); vol. 49, 1917, pp. 356–60 (Speight).

Quart. Jour. Geol. Soc., vol. 41, 1885, pp. 547–64 (Hutton, on the "Curiosity Shop" beds).

N.Z. Geol. Surv. Bull. No. 1, 1906 (a few pages refer to the crest of the Southern Alps, and the Wilberforce Goldfield, which is in Selwyn County). N.Z. Geol. Surv. Bull. No. 6, 1908 (this contains references to the crest of the Alps, Mathias Pass, Whitcombe Pass, &c.).

Woods, Henry: "The Cretaceous Faunas of the North-eastern Part of the South Island of New Zealand." N.Z. Geol. Surv. Pal. Bull. No. 4, 1917 (see pp. 16, 17, &c.).

32. Ellesmere County.

Ellesmere County forms part of the great Canterbury Plain. Having good road and railway communications, it can easily obtain supplies of lime from outside sources.

33. Ashburton County.

Ashburton is a large county, extending from the Southern Alps to the sea, and from the Rakaia to the Rangitata River. Nearly one-half the county is mountainous; the remainder forms part of the Canterbury Plain, which is here most typically developed. The mountains consist mainly of greywacke and argillite of old Mesozoic age. They enclose some very large intermontane valleys and basins, the most notable of which is that in the Lake Heron district. According to von Haast's geological map this basin links up the Rangitata and Rakaia watersheds. Moreover, it is crossed by the Ashburton River, which with commendable independence apparently has preferred to cut its way through the mountains to the east rather than flow southward to join the Rakaia River. The Mackenzie Plain, farther south, is a still more notable example of an intermontane basin than the Lake Heron region. The Canterbury intermontane basins contain many lakes. Thick gravel deposits, partly of fluviatile and partly of glacial origin, cover their floors. The origin of these basins is comparatively simple. They have been formed by means of a very general uplift along the eastern margin of the Canterbury mountains, possibly combined with some depression farther inland. Everywhere great faults mark the eastern boundary of the mountains. Numerous comparatively minor movements of faulting, tilting, and warping have subdivided the mountain area into blocks, and have given rise to various minor basins. The shapes of these have been modified by stream and ice erosion, but it is important to guard against the impression that they have been scooped out by ice, which was the general explanation advanced by von Haast (1865, 1879, &c.). It is desirable also not to speak of the basins as depressions, except in those cases where down-faulting or warping has been distinctly proved, for the upward movement of the outer margin would produce the same or at least similar effects. Neither ought one to assume that until recently they have been wholly occupied by lakes, for in many cases the rivers and glaciers filled the hollows with gravel as fast as they were formed.

Among the Ashburton County mountains, and on their outer margin, are various patches of Tertiary strata, and in many places there are also masses of igneous rocks, probably of Cretaceous and Tertiary age. According to von Haast, Cretaceous sediments are seen only on the south bank of the Rakaia River, at Rakaia Gorge.

The Tertiary rocks include more or less limestone, which is seen in some abundance near the foot of the hills on both sides of the south branch of the Ashburton River. According to von Haast (1877 report, p. 16, and "Geology of Canterbury and Westland," pp. 307–8) the best section of the Tertiary strata is to be observed on the northern bank of the Ashburton, between Limestone Bluff and the Two Brothers. On the summit of the ridge is 15 ft. of white flaggy limestone, consisting principally of pieces of shell and "corals" (? Bryozoa). It passes downward into arenaceous limestone 70 ft. in thickness, underlain by volcanic tufa and greensand, below which is 10 ft. of shell limestone, in several layers. Under this are beds of sand, which may be valuable for glassmaking. These strata strike east of north and dip at 55° to the east-south-east, so that they are evidently more or less fault-involved. South of the Ashburton, near Mount Somers, limestone is extensively developed, and is quarried as a building-stone. It is a somewhat soft stone, resembling the Oamaru stone, but is generally of a pinkish or reddish tinge. The Mount Somers stone is also used for making lime. The works, according to a newspaper report, are owned by Messrs. Blackburne, Smith, and Co., of Christchurch.

In November, 1917, one of the writers visited a locality near Springburn, north of Mount Somers, where a lime-kiln was operated until about six years ago. The limestone adjoining the kiln was apparently of good quality, and, with included layers of sandstone, about 90 ft. thick. Characteristic Miocene fossils were present. The strike was nearly magnetic north and south (*i.e.*, east of north), and the dip 85° to the westward. It was apparently overlain by brown sandstone, but very probably the beds were overturned. Analyses Nos. 2, 3, 4, and 7 of the table in a later paragraph probably represent samples from this locality.

Calcareous rocks appear at Coal Creek, on the south bank of the Rangitata, and an outlier of similar nature occurs at the head of the northern branch of the Hinds in the so-called Limestone Range (von Haast, 1877 report, pp. 17–18, and "Geology of Canterbury and Westland," pp. 308–9).

On the eastern side of the Palmer Range, near Lake Heron, are Tertiary beds containing two bands of shell limestone, each 4 ft. thick, separated by 6 ft. of sand. Similar beds occur at other localities in the same district (von Haast, 1877 report, pp. 18–19).

In Redcliff* Gully, on the south bank of the Rakaia River opposite Lake Coleridge, is a small outlier of Tertiary sandstones and limestone. The latter rock is "pinkish in colour, somewhat crystalline in character, flaggy in the lower parts, but more compact and even, and breaking into cuboidal blocks towards the top. . . . The thickness is at least 150 ft." (Speight, 1913, p. 338). Calcareous sandstone and shell-beds overlie the limestone, and it is underlain by light-coloured sands which pass into a thick stratum of greensand. These strike to the east-north-east, and dip at an angle of 55° to the west of north.

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* In some old reports the name is spelt "Redcliffe."

The following analyses of limestone from Ashburton County have been found in the literature consulted :—

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid	1·29	14·01	9·87	2·25	..	..
Soluble silica	..	..	..	..	..	..
Silicates, &c.	..	..	..	..	..	..
Alumina	0·21	3·14	6·22	1·39	..	..
Iron oxides	Traces					
Calcium carbonate	95·75	79·79	80·78	93·24	94·76	98·27
Magnesium carbonate	2·64	2·86	2·89	2·96	..	..
Water	0·11	0·20	0·24	0·16	..	..
	100·00	100·00	100·00	100·00	..	..

	(7)	(8)	(9)	(10)	(11)	(12)
Matter insoluble in acid	..	33·20	1·5	1·0	6·1	6·7
Soluble silica	..	4·74	1·0	0·2	1·3	4·2
Silicates, &c.	..	..				
Alumina	..	5·75				
Iron oxides	..					
Calcium carbonate	88·35	51·57	96·0	96·0	90·0	87·0
Magnesium carbonate	..	2·96	1·0	1·5	1·3	1·3
Water	..	1·78	0·4	1·1	1·3	0·9
	..	100·00	99·9	99·8	100·0	100·1
Specific gravity (as calculated from weight of 6 in. cubes)	..	..	2·01	1·48	1·95	1·49

References.—(1) Crystalline limestone, forwarded by Mr. A. E. Peach, of Ashburton. Col. Mus. and Lab. 19th Ann. Rep., 1885, p. 26. Lab. No. 3685. Probably from Mount Somers.

(2) to (4) Granular limestones from Reid's Creek, near Alford Forest, four miles from Springburn; forwarded by Mines Department. Col. Mus. and Lab. 27th Ann. Rep., 1893, p. 23. Lab. Nos. 5964/1–3. See also Mines Rep., C.–3, 1892, p. 139. Nos. 5964/1 and 5964/3 had a light stone colour; No. 5964/2 was of a red rusty appearance. The impurities consisted of fine green, black, and yellow sand (? glauconite and quartz sand). Other particulars are given by the analyst.

(5) Mount Somers. B. C. Aston, Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 331. Analyst's number and date, G 172, 1915. Nos. 6 and 7 have the same reference.

(6) Cavendish, near Mount Somers. Analyst's No. G 171.

(7) Staveley, near Springburn. Analyst's No. G 173.

(8) Impure limestone from Mount Potts, collected by Mr. Alex. McKay (Geol. Surv.). Col. Mus. and Lab. 14th Ann. Rep., 1879, p. 25. Lab. No. 2099.

(9) From Peache's (? Peach's) quarry, Mount Somers; exhibited by W. Stocks. Black, J. G.: "Official Record of the N.Z. and South Seas Exhibition, Dunedin, 1889–90" (Wellington, 1891), pp. 368, 369, 371. Analyst's No. 10.

(10) From Mount Somers; exhibited by E. F. Wright. Same reference as No. 9, pp. 368, 370, 371. Analyst's No. 13.

(11) From Mount Somers; exhibited by N.Z. Stone Company. Same reference as No. 10. Analyst's No. 15.

(12) Pink limestone from Mount Somers; exhibited by Public Works Department. Same reference as Nos. 10 and 11. Analyst's No. 25. Sum of constituents as given in report cited, 101·1.

The Canterbury Plain.

The Canterbury Plain extends from a point some miles north of Waipara to Washdyke, near Timaru, a distance of nearly 120 miles. It is widest in Ashburton County, where its width approaches thirty-five miles, and was once greater, for the sea has cut back the original coast so far as to form a cliff with a maximum height of 70 ft. (von Haast). The plain has been formed by the accumulation of detritus carried by the various streams draining the Alps, and deposited by them on issuing from the mountain region in the form of huge fans, which finally coalesced to form a continuous plain with a gently sloping surface. The lowest layers may have been deposited in the sea, but it is certain that the material of the plain is purely fluviatile to a depth of many hundred feet, except near some portions of the present coast-line. The view just set forth was enunciated by von Haast, but was strongly combated by Hutton, who maintained that the plain was wholly formed of material deposited in the sea during a period when the land was rising. He believed that the central portion of the plain had risen at least 1,700 ft. since the beginning of the Pleistocene period, and pointed to raised beaches in northern Canterbury as a proof that the sea was once 300 ft. (or he might have said 500 ft. to 600 ft.) higher than it now is. Hutton, however, stood almost alone in his views, and abundant evidence is now forthcoming to show that von Haast's view was correct. Since the formation of the plain began there has been depression of the land, not elevation (except to a very small extent). The raised beaches mentioned by Hutton are considered by Speight to be connected with elevation preceding the period of depression during which the plain was formed. The petroleum-bore at Chertsey at a depth of 1,500 ft., or 1,150 ft. below present sea-level, was still in gravel, sand, and clay that appeared to be of fluviatile origin. In this bore, however, there was a change between 500 ft. and 600 ft., and it is possible that the lower gravels belong to a somewhat older geological period than the upper gravels, and are separated from them by an unconformity. The literature dealing with the Canterbury Plain is listed below.

The plain of northern Italy has been formed in the same way as the Canterbury Plain, and that part north-east of Venice where the Italians and Austrians were till lately engaged in deadly conflict bears a striking resemblance to it. The Tagliamento and Piave rivers may be compared to the Waimakariri, Rakaia, and Rangitata rivers in almost every respect. The swamps towards the mouths of the Italian streams, however, are perhaps somewhat poorly paralleled by the low ground at the mouth of the Waimakariri. An intensive study, however, of the Canterbury Plain and of the adjoining mountain regions would enable a soldier quickly to acquire the special topographical knowledge necessary for directing a military campaign in the province of Venetia.

Summary of Limestone Resources and of Means of Transport.

Ashburton County appears to have fair limestone resources, but further exploration and systematic sampling of outcrops are necessary in order to obtain precise information. The Christchurch–Dunedin Railway traverses the county at an average distance of somewhat over ten miles from the coast. Branch railways from Rakaia and Ashburton run inland to Methven and Springburn respectively. The lowland part of Ashburton County is well roaded, so that the distribution of lime will offer no difficulty. The principal intermontane basins and valleys seem to be fairly accessible by means of roads up the main river-valleys.

Literature.

The chief publications relating to the Canterbury Plain are—

Haast, Julius von: "Report on the Formation of the Canterbury Plain . . ." Christchurch, 1864 (Provincial Government paper); "Geology of Canterbury and Westland," 1879, pp. 63, 396–406, &c.

Rep. of Geol. Explor., No. 8, 1877, pp. 56–58 (Hutton).

Trans. N.Z. Inst., vol. 5, 1873, pp. 387–89 (Hutton); vol. 6, 1874, pp. 421–24 (von Haast); vol. 16, 1884, pp. 449–54 (Hutton); vol. 39, 1907, pp. 206–12 (F. W. Hilgendorf); vol. 40, 1908, part of pp. 16–43 (Speight).

Hutton, F. W.: "Geology of Otago," 1875, pp. 91–92.

Marshall, P.: "The Geography of New Zealand" (1905), pp. 108–9.

Park, James: "The Geology of New Zealand," 1910, p. 242.

Other references to the geology of Ashburton County are—

- "Geology of Canterbury and Westland," pp. 60–62, 128–29, 262, 268–73, part of pp. 285–90, pp. 307–9, 313, 386 *et seq.*, 463, 464, 466, &c.
- Rep. of Geol. Explor., No. 7, 1872, pp. 141–46; No. 8, 1877, pp. 1–19; No. 10, 1877, pp. vi–vii, 1–10; No. 11, 1878, pp. iv–vii, 91–109; No. 16, 1884, parts of pp. xx–xxii, 22–43, 107–9; No. 21, pp. 15–16, 146–47.
- Mines Rep., Parl. Paper C.–3, 1892, pp. 139–40.
- Trans. N.Z. Inst., vol. 43, 1911, pp. 317–42 (Speight); vol. 45, 1913, pp. 335–41 (Speight); vol. 47, 1915, pp. 345–46 (Speight); vol. 48, 1916, part of pp. 137–44 (Speight).

34. MACKENZIE COUNTY.

Mackenzie is a large inland county extending eastward from the Southern Alps to within twelve or fourteen miles of Timaru. It contains Mount Cook (12,349 ft.), the highest mountain in New Zealand, and also the great inland basin known as the Mackenzie Plains, which contains, or partly contains, three large lakes, but by no means consists wholly of flat country. Except where fluviatile or glacial gravels cover the surface of the county, the rocks exposed are mainly greywackes and argillites of supposed old Mesozoic age. Igneous rocks in the ordinary sense of the term are unknown, but the ice of the various glaciers in the alpine region must be regarded as an igneous rock, for it can hardly be excluded from any definition of that term ever framed. Tertiary rocks are poorly represented in the county. They occur (1) as a strip along the eastern face of the Hunter's Hills, southward from the Opihi River; (2) as a small patch towards the head of the Opuha River, south of Tripp's Pass; (3) as several small patches on or near the north bank of the Opihi River; and (4) between the lower Opuha and Opihi rivers, as part of a large area extending into Geraldine and Levels counties. The available information concerning limestone in the Tertiary rocks is scanty. Apparently it appears more or less continuously in the strip on the east side of the Hunter's Hills.

Some further information will be obtained from a paper by M. C. Gudex, which appears in Trans. N.Z. Inst., vol. 50, 1918, pp. 244–62, and deals with the area between the Otaio and Tengawai rivers, which is partly in Waimate and partly in Mackenzie County (see especially pp. 255–56 and 253–59 (Cannington's)). The paper is illustrated by some good sections and photographs, but the map on page 247 is poorly drawn, and inadequate from a topographical point of view.

The following analyses are believed to represent samples from localities in Mackenzie County west of Albury, except the last, which is from the Fairlie district:—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Carbonate of lime	74·92	76·00	77·05	56·48	82·21	82·72	83·02	69·20
Carbonate of magnesia ..	3·04	3·17	4·03	2·06	2·94	2·86	2·64	..
Sulphate of lime	..	..	..	..	0·13	0·11	0·10	..
Alumina and iron oxides ..	3·63	3·02	4·12	0·41	1·41	1·64	1·71	..
Matter insoluble in acid ..	18·20	17·63	14·49	40·81	12·26	11·36	11·49	..
Water	0·21	0·18	0·31	0·24	0·23	0·30	0·40	..
Alkalies and loss	..	..	..	..	0·82	1·01	0·64	..
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	..

References.—(1) to (3) From Albury, forwarded by Mr. E. Richardson, jun. Col. Lab. 28th Ann. Rep., 1894, p. 13. Lab. No. 6480. According to Skey these are fairly good freestones (adapted for building), and, he thinks, when crushed would greatly benefit non-calcareous soils.

(4) Sandy limestone from Albury, forwarded by Mr. Straw. Col. Lab. 29th Ann. Rep., 1895, p. 12. Lab. No. 6810.

(5) to (7) Fine granular fairly compact limestones from the Albury Estate, forwarded by the Hon. Mr. W. Hall-Jones. Col. Lab. 34th Ann. Rep., 1901, pp. 11–12. Lab. Nos. 8681/1–3. These are " very calcareous freestones, and so especially fitted for building purposes." Broken down well they should be found " very fertilizing to heavy soils deficient in lime." They should be tried in the kiln to ascertain whether they would burn to good lime.

(8) From Fairlie. B. C. Aston, Jour. Agric., No. 4, Oct., 1915, p. 331. Analyst's number and date, G166, 1915.

Analyses of limestone from Cave and the Upper Pareora River are quoted under Waimate County.

Summary of Limestone Resources and of Means of Transport.

Exploration is necessary in order to ascertain the limestone resources of Mackenzie County, which, however, are probably not great, except possibly in the district east of Fairlie. The limestone on the eastern side of the Hunter's Hills is generally not sufficiently pure for calcination, but when pulverized will be useful as a soil-dressing.

A railway extends along the eastern boundary of the county from Cave to Fairlie. It connects with the main railway system of the South Island at Timaru, and enables lime to be obtained from other parts of South Canterbury or from the Oamaru district. When its mountainous nature is considered Mackenzie County appears to be well provided with roads, the best known being the coach and motor road from Fairlie to the Hermitage, Mount Cook district.

Literature.

There are numerous publications dealing with the glaciers and mountains of Mackenzie County. The chief references to the geology are the following:—

Rep. of Geol. Explor., No. 6, 1871, pp. 19–24; No. 10, 1877, p. 51; No. 14, 1882, pp. 59, 77; No. 21, 1892, pp. 16–17, 153 (Geraldine County).

Trans. N.Z. Inst., vol. 10, 1878, pp. 481–84; vol. 37, 1905, pp. 531–32; vol. 47, 1915, p. 346; vol. 50, 1918, part of pp. 244–62 (M. C. Gudex).

" Geology of Canterbury and Westland," 1879, pp. 18–43, 58, 199–205, 262, 280, 384–86, 466, &c.

Kitson, A. E., and Thiele, E. O.: " The Geography of the Upper Waitaki Basin, New Zealand." *Geographical Journal*, vol. 36, November, 1910, pp. 537–53.

35. GERALDINE COUNTY.

The geology of Geraldine County is similar to that of Ashburton County. Old Mesozoic greywackes and argillites (with some limestone or marble) form most of the mountainous interior, whilst the rest of the county is part of the Canterbury Plain A gravel-floored basin occurs in the Upper Orari Valley. Sedimentary rocks of Tertiary age are much better developed than in Ashburton County. They form a strip stretching in a north-and-south direction from the Orari River along the eastern front of the Four Peak Range, where it broadens and extends into Mackenzie and Levels counties. Several small isolated patches of Tertiary rocks (including some volcanic material) occur east of the Four Peak Range on the Canterbury Plain, and outliers are found in the Upper Orari Valley on the south-east side of the basin mentioned above. In most localities a fairly thick band of somewhat impure limestone forms part of the Tertiary strata.

Hard blue or white crystalline limestone or marble occurs interbedded with the ancient Mesozoic rocks forming the Kakahu Gorge. Attempts to use it as a building-stone have been commercially unsuccessful. Many years ago kilns were erected in order to burn the stone, but after a time the enterprise was abandoned. The Mesozoic limestone or marble is largely of high quality, as is shown by the following analyses :—

	(1)	(2)	(3)
Carbonate of lime ($CaCO_3$)	95·72	95·18	93·49
Carbonate of magnesia ($MgCO_3$).. ..	2·01	2·96	3·49
Alumina (Al_2O_3)	1·39	0·34	0·61
Iron oxides (FeO and Fe_2O_3)	Traces		
Silica, or matter insoluble in acid ..	0·80	1·31	2·17
Water	0·08	0·21	0·24
	100·00	100·00	100·00

References.—(1) Blue limestone from Kakahu, forwarded by Mr. J. D. Enys. Col. Mus. and Lab. 16th Ann. Rep., 1882, p. 30. Lab. No. 2852/1. Another sample (Lab. No. 2852/2), stated to be from Mount White River, is of very similar composition. It is supposed to have come from Tawera County (see p. 232), but possibly is from South Canterbury.

(2) Light-coloured granular subcrystalline limestone from Kakahu, collected by Mr. James Park (Geol. Surv.). Col. Mus. and Lab. 21st Ann. Rep., 1886, p. 36. Lab. No. 4122/1 (or 4123/1, p. 59).

(3) Grey limestone, similar to No. 2 above. Same locality, collector, and reference. Lab. No. 4122/2 (or 4123/2).

Tertiary limestone occurs at many points in the Kakahu and Opuha valleys, where it forms a U-shaped belt round the southern end of the Four Peak Range. In the Kakahu district the limestone is 100 ft. thick, and is correlated by McKay (1877 report, pp. 59–60) with the Weka Pass stone (Waipara County). It is apparently sandy, and not of high quality. The following analyses probably all represent limestone of Tertiary age :—

	(1)	(2)	(3)	(4)
Matter insoluble in acid	19·64	..	..	..
Alumina and iron oxides ..	0·76	..	..	..
Calcium carbonate	76·91	79·48	69·90	72·78
Magnesium carbonate	2·69	..	..	..
	100·00	..	..	..

References.—(1) From lower gorge of Kakahu, collected by Mr. Alex. McKay. Col. Mus. and Lab. 21st Ann. Rep., 1886, p. 37. Lab. No. 4118.

(2) to (4) From Kakahu, Upper Te Moana, and Upper Waitohi respectively. Aston, B. C., Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 331. Analyst's numbers and date, G 167, 169, 170 ; 1915. G 170 (Upper Waitohi) was a " soft " limestone with 14·64 per cent. of moisture (A. McTaggart, same volume, No. 5, Nov., 1915, p. 399).

A sample (G 168) of " marl " from Kakahu contained 7·03 per cent. of calcium carbonate (Aston, as cited above, p. 331).

Summary of Limestone Resources and of Means of Transport.

Geraldine County has extensive limestone deposits, but only the Mesozoic marble of the Kakahu Gorge is known to be of high quality and suitable for calcination. The Tertiary limestone, being of medium grade, will require pulverization to enable it to be used for agricultural purposes. At Upper Waitohi is a deposit of " soft " limestone of good quality, which, however, is not very well situated with respect to the railway (A. McTaggart).

The eastern or coastal part of the county is traversed by the Dunedin–Christchurch Railway, and is well roaded. The mountainous area is reached by roads up the Orari and Rangitata valleys.

Literature.

The chief references to the geology of Geraldine County are—

Rep. Geol. Explor., No. 10, 1877, pp. 46, 47, 53, 54, 55, 59, 60, 61, 62, 63, 64 (part of pp. 40–66, a report by McKay); No. 17, pp. 170–78 (Park); No. 18, 1886, pp. 92, 93, 96, 98, 100 (McKay); No. 21, 1892, p. 153.

"Geology of Canterbury and Westland," 1879, pp. 263, 265, 293, 309, 317, 462, &c.

Trans. N.Z. Inst., vol. 37, 1905, pp. 532–34 (Park).

36. Levels County.

A small area of old Mesozoic rocks occurs in the west of Levels County. East of this is a low hilly district, composed of Tertiary sedimentary rocks and, near Timaru, of basalt. Quaternary gravels and clays cover considerable areas near the Pareora River and Timaru. The northern part of the county forms the extreme southern part of the Canterbury Plain.

Limestone occurs in the Tertiary rocks near Pleasant Point and Sutherland's. Escarpments of this rock occur near Cave, on the border of Mackenzie County; and at the foot of the cliffs is a slope or talus deposit containing limestone of rather poor quality (A. McTaggart, Jour. Agric., vol. 11, 1915, p. 394). Limestone probably occurs east of Albury, but the writers have no precise information, and have assigned all the analyses of limestone from the Albury district to Mackenzie County, a course followed also by B. C. Aston.

The following analyses are believed to refer to samples from Levels County:—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Matter insoluble in acid, &c.	15·41	30·8	7·5	..	..	..	..
Soluble silica	0·42						
Alumina	..	7·8	3·7	..	..	..	..
Iron oxides	0·29	2·1	3·6	..	..	..	..
Calcium carbonate	79·54	49·6	79·5	87·22	65·64	83·66	23·56
Magnesium carbonate	2·99	1·5	1·9	..	..	..	..
Calcium oxide (CaO)	..	2·6	1·3	..	..	..	..
Organic matter	0·61	5·6	2·5	..	..	..	..
Water	0·74						
	100·00	100·0	100·0	..	..	..	..
Lime (CaO) in calcined stone (per cent.)	66·6	42·4	74·5	..	..	..	..

References.—(1) Light-brown finely granular calcareous freestone from "Timaru," forwarded by the Hon. E. Richardson. Col. Mus. and Lab. 14th Ann. Rep., 1879, p. 27. Lab. No. 2114. The analyst (W. Skey) remarks that the stone is porous when freshly fractured, but hardens on exposure. It is a free-working stone, without cracks or cleavages. One cubic foot weighs 105 lb., and the specific gravity of the dry stone is 1·691, of the water-soaked stone 1·741. Its resistance to crushing exceeds 160 lb. per square inch.

(2) (3) From "Timaru," forwarded by Mrs. Marie Squire. Col. Lab. 40th Ann. Rep., 1907, pp. 16–17. Lab. Nos. 560/1, 2. The composition of the burnt (calcined) stone is also given. "Squire's farm," mentioned by Gudex (see below), is in Waimate County, and these samples may have come from that locality.

(4) From Upper Pareora River. Aston, B. C., Jour. Agric., as previously cited, p. 332. Analyst's number and date, G 162, 1915. The sample may be from Waimate or Mackenzie County.

(5) (6) From Cave. Aston, B. C., as cited above. Analyst's numbers and date, G 163, 164; 1915.

(7) Soft limestone, from Limestone Valley, near Cave. Aston, B. C., as cited above. Analyst's number and date, G 165, 1915. See also A. McTaggart, same volume, p. 398. Very low-grade material. Ascribed to Sutherland's by Aston.

A recent paper by M. C. Gudex describes the limestones of the Pareora district somewhat fully. The principal area in Levels County mentioned is Tycho Valley, west of Mount Horrible, where Gudex maps a strip of limestone on the west side of the valley, on the slopes of Mount Misery.

Summary of Limestone Resources and of Means of Transport.

Further exploration and sampling are needed in order accurately to gauge the limestone resources of Levels County. The deposits appear to be considerable, and some are situated in accessible positions near the railway from Timaru to Fairlie. The quality, however, is moderate, and probably the stone in most localities is better suited for pulverization than for calcination. Naturally pulverized or " soft " limestone appears to occur near Cave in Limestone Valley, and perhaps elsewhere. According to Mr. A. McTaggart the deposit in Limestone Valley is extensive, but is not handily situated with respect to the railway (Jour. Agric., vol. 11, 1915, p. 394).

Levels County has good railway and road communications, and also contains the artificial harbour of Timaru, which now offers good accommodation to shipping.

Literature.

The chief references to the geology of Levels County will be found in the following list :—

Haast, Julius von : " Report on the Geological Formation of the Timaru District, in reference to obtaining a Supply of Water," Christchurch, 1865. " Geology of Canterbury and Westland," 1879, pp. 220, 314, 316 (Pareora Formation), &c.

Rep. of Geol. Explor., No. 10, 1877, pp. 49, part of pp. 54–60, 66.

Trans. N.Z. Inst., vol. 19, 1887, pp. 455–58 (John Goodall) ; vol. 22, 1890, pp. 406–14 (J. Hardcastle) ; vol. 23, 1891, pp. 311–32 (J. Hardcastle), 366–72 (H. O. Forbes) ; vol. 37, 1905, pp. 530–31 (Park) ; vol. 50, 1918, part of pp. 244–62 (M. C. Gudex).

37. WAIMATE COUNTY.

Waimate is a fairly large county with a diversified surface. The inland portions consist mainly of old Mesozoic greywackes and argillites, but in places these contain a fossil considered by McKay (1882 report, p. 78) to be the Dun Mountain " *Inoceramus* " (i.e., *Aphanaia*). If so, the containing rocks are of Permo-Carboniferous age. There are numerous patches of Tertiary sedimentary rocks, most of which include calcareous strata, scattered about the county. The largest of these are on the south side of the Upper Pareora and in the upper valley of the Waihao River. A considerable plain reaches from the Pareora River in the north to the Waitaki River in the south. This extends well up the Waitaki Valley. A considerable inland basin, gravel-floored, is drained by the Hakataramea River.

A few miles south-west of Waimate a narrow belt of limestone from 50 ft. to 100 ft. thick forms cliffs for several miles along the southern side of the Waihao River, near Waihao Forks and Arno (McKay, 1886 report, p. 104), and extends westward for another four miles. Limestone occurs also in patches on the north side of the river. The stone is highly glauconitic, and in its lower part consists of thin beds of hard limestone separating thicker bands of highly calcareous greensand. Marly rock is reported to underlie the limestone near McCulloch's Bridge (Thomson, 1914 report, p. 160). A small area of limestone (probably of good quality) occurs also far inland on the north bank of the Waitaki River, opposite Wharekuri. The following analyses all represent limestone or other calcareous rock from the Waihao district :—

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid	25·42	6·01	..	..	..	16·3
Alumina and iron oxides	1·82	1·64	..	..	..	
Calcium carbonate	69·69	89·04	90·25	64·58	29·10	81·0
Magnesium carbonate	2·43	2·98	..	..	..	0·8
Water	0·64	0·33	..	..	..	1·0
	100·00	100·00	..	..	..	99·1
Specific gravity, calculated from weight of 6 in. cube	..	..	..	..	..	1·65

References.—(1) Limestone with siliceous bands from Waihao Downs, forwarded by Mr. T. L. Douglas. Col. Lab. 28th Ann. Rep., 1894, p. 11. Lab. No. 6204/1.

(2) Limestone free from siliceous bands. Same contributor and reference as No. 1. Lab. No. 6204/2.

(3) (4) From Waihao Downs. Aston, B. C., Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 331. Analyst's numbers and date, G160, 161 ; 1915.

(5) From McCulloch's Bridge, Waihao River. Same reference as Nos. 3 and 4. Analyst's number and date, G159, 1915. Probably a calcareous sandstone, but may represent the marl mentioned by Thomson.

(6) Fine-grained limestone from Waihao Downs, exhibited by J. Douglas. Black, J. G., in " Official Record of the N.Z. and South Seas Exhibition, Dunedin, 1889–90 " (Wellington, 1891), pp. 369, 371.

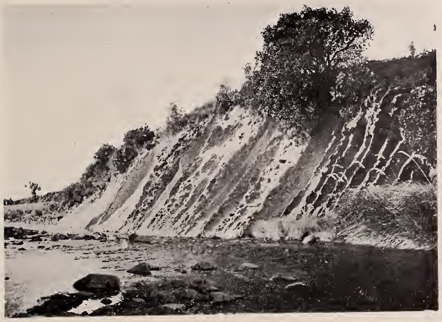
It may be noted that four analyses (Lab. Nos. 2026/1–4) quoted by Aston are ascribed to Waimate County, but actually represent samples from the Waimate district, Whangaroa County, North Auckland.

The following analysis is said to represent chalk from some part of South Canterbury, but probably refers to a dried sample of " soft " limestone :—

Carbonate of lime	84·12
Carbonate of magnesia	2·10
Clay	12·57
Iron oxides and alumina, soluble in acid	1·21
	100·00

Reference.—Forwarded by Mr. H. Higginson. Col. Mus. and Lab. 11th Ann. Rep., 1876, p. 17. Lab. No. 1767/*a*.

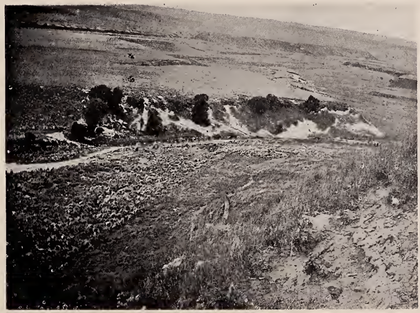
In vol. 50 of Trans. N.Z. Inst., 1918, Mr. M. C. Gudex describes an area with several patches of limestone in the north of Waimate County, between the Otaio and Upper Pareora rivers. His map (p. 247) shows a block of limestone north of White Rock Stream which extends across the Upper Pareora into Mackenzie County. A strip of limestone appears on the western side of the Little Pareora Valley, at its junction with the main valley, and stretches south-west for several miles. Limestone occurs on both sides of the Pareora River below the junction of the Little Pareora. The same rock covers a considerable area on the south-east side of the Little Pareora, and extends to Gordon's Valley, on the south side of which is more limestone, reaching almost to the Otaio River. At Otaio Gorge, where the Otaio emerges from the Hunter's Hills, the limestone and associated sands, marls, &c. (? fault-involved), dip at 60° to the east-north-east. At Squire's farm, on the banks of the Little Pareora River, near the Hunter's Hills, a section showing 4½ ft of dark limestone, 14 ft. or more of white flaky limestone, and a considerable but undetermined thickness of " current-bedded " limestone of the usual type is exposed. The beds dip at 40° to the north-east. Farther north a small patch of limestone lies close in against the greywackes of the Hunter's Hills.



A. View of the Fluted Limestone at Otaio Gorge.

Almost the whole thickness of the limestone is shown.

[*From a paper by M. C. Gudex in vol. 50, Trans. N.Z. Inst.*]



B. The Upper Part of Little River Valley, viewed from Squire's Farm.

The rock in the foreground is the uppermost part of the limestone, with soft layers. In the middle distance, on the left, the white flaky limestone is seen passing up into the dark and ordinary limestones, which in turn pass up into the blue clay.

[*From a paper by M. C. Gudex in vol. 50, Trans. N.Z. Inst.*]

The usual type of limestone in the district described by Gudex is arenaceous, more or less glauconitic, and yellowish to greenish-white in colour. The layers are generally of varying hardness, so that weathering causes a characteristic fluted appearance. When followed to the eastward (of the Hunter's Hills) the rock becomes less arenaceous (sandy), but "more compact and siliceous"—a statement that presumably means that the impurities increase, but are fine-grained, as would be the case at some distance from the old shore-line. The thickness, however, increases from 55 ft. to 100 ft. There are numerous caves and solution-pits in the more easterly areas.

Summary of Limestone Resources and of Means of Transport.

Waimate County possesses very considerable limestone resources. The tonnage in several of the deposits described above is large. Thus the strip of limestone exposed on the south side of the Waihao River may be expected to contain at least 50,000,000 tons of rock, and almost countless millions of tons exist to the dip. The quality of the Waimate County limestone, however, is variable, and probably the average sample is better adapted for pulverization than calcination.* If bands of good quality can be found and conveniently quarried, transport will offer no difficulty, since the branch railway from Studholme Junction already practically taps the limestone at its terminus (Waihao Downs). Clearly, more exploration and sampling by a qualified person are necessary in order to enable the limestone resources of the county to be appraised. The coastal strip of Waimate County is traversed by the Dunedin–Christchurch Railway, which is joined at Studholme by the branch from Waihao Downs and Waimate already mentioned. The branch railway from Pukeuri to Kurow, on the south side of the Waitaki River, gives access to the Hakataramea district, but is not of much value to the country eastward of Hakataramea, owing to the lower Waitaki not being bridged except near its mouth. The eastern part of Waimate County is well roaded. Several roads penetrate into the interior, but these need not be specially described.

Literature.

The chief references to the geology of Waimate County will be found in the following publications :—

Rep. of Geol. Explor., No. 10, 1877, part of pp. 49–60 (McKay); No. 14, 1882, parts of pp. xxi-xxvii, 56–92 (McKay), especially pp. 62, 65, 66, 70–73, 76, 77, 78, 79, 83–86; No. 17, 1886, pp. xii, 21–22 (A. B. Lindop); No. 18, 1887, pp. 91–119 (McKay); No. 21, 1892, p. 168.

"Geology of Canterbury and Westland," 1879, pp. 199–205 (part), 220, 263, 265, 309–10, 317, 459, &c.

Trans. N.Z. Inst., vol. 19, 1887, pp. 430–33 (Hutton), 434–40 (McKay); vol. 20, 1888, pp. 264–67 (Hutton); vol. 37, 1905, pp. 527–31 (Park); vol. 47, 1915, pp. 380–83, 385–86 (Marshall).

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.-2, 1914, pp. 158–62 (J. A. Thomson). 2nd ed., 1915.

38. WAITAKI COUNTY.

Waitaki County is a long curved strip of country reaching from Mount Percy Smith in the Southern Alps to the sea. Much of this area is mountainous, and almost or quite uninhabited, but the lower Waitaki Valley and the coastal belt contain much fine agricultural land, and are well settled.

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* A lime-kiln has been built in the Little Pareora Valley (Gudex, 1918, p. 257), but no particulars concerning its output, &c., have been ascertained.

The oldest rocks of the county appear to be the schists and subschistose rocks which are seen in the far north-west of the county west of Lake Ohau, and appear as small patches comparatively near the coast in the neighbourhood of Peebles, Black Point, Big Hill, &c. McKay in 1882 indicated the existence of Maitai (*i.e.*, Permo-Carboniferous) rocks on the Otago side of the Waitaki River above the junction of the Kurow, and in 1894 mapped the greater part of the county as consisting of Carboniferous and Devonian rocks. In 1904 Park announced the discovery of characteristic Permo-Carboniferous fossils on Mount St. Mary, west of Kurow, but in 1910 advanced the view that the fauna was Permo-Triassic. Old Mesozoic greywackes and argillites (possibly with some limestone—see Waihemo County) are probably present in the Kakanui Mountains and elsewhere. Near Shag Point and in the Horse Range (a continuation of the Kakanui Range) Cretaceous conglomerates, sandstones, shales, and calcareous claystones appear.

Middle Tertiary conglomerates, sandstones, limestones, and calcareous claystones are well developed on the south side of the Waitaki Valley and near the coast. Volcanic rocks are interstratified with the Tertiary strata near Oamaru, and are seen in many localities farther south, especially in the Moeraki Peninsula. From Oamaru to the Waitaki River is a coastal plain, a prolongation of that seen in Waimate County. It continues up the Waitaki for many miles as a gravel-covered river or flood-plain, bordered by terraces. Far up the Waitaki are the Waitaki and Ahuriri plains, which form a southern continuation of the Mackenzie Plain or basin.

The Permo-Carboniferous or Triassic rocks (Mount St. Mary Series) of Waitaki County are calcareous in places, and possibly the hard blue limestone known to exist in Block X, Ngapara Survey District, belongs to that series.*

The Cretaceous rocks exposed along the coast-line near Hampden and south of Moeraki contain numerous concretions of all sizes. These are commonly known as Moeraki boulders, and are frequently mentioned in geological literature. Many of them illustrate the structure known as cone-in-cone limestone very well, this material usually surrounding the concretions *in situ* (McKay, 1887, p. 6). Fifty years or more ago attempts to manufacture "natural" cement from them were made, but these were soon abandoned, and, in the light of modern methods of making Portland cement, are not likely ever to be renewed. The following analyses show the composition of the concretions :—

	(1)	(2)	(3)
Carbonate of lime	66·7	72·4	50·8
Carbonate of magnesia	..	0·3	..
Alumina and iron oxides	15·1	8·7	7·6
Soluble silica	16·2	0·8	..
Sand and clay		17·8	41·6
Organic matter	2·0	..	..
Water	..	0·6	..
	100·0	100·6	100·0

References.—(1) Quoted from G. A. Mantell (1850) by A. Hamilton in Trans. N.Z. Inst., vol. 34, 1902, p. 450. Alumina is given as 10·4, peroxide of iron as 4·7, and silica as 16·2.

(2) Analysis of whole mass of a "Moeraki boulder." Col. Mus. and Lab. 6th Ann. Rep., 1871, pp. 28–29. See also "Reports and Awards of the Jurors, N.Z. Exhibition, 1865, Appendix A," 1866, pp. 420–21.

(3) Analysis of "Moeraki boulder" freed from calcareous (calcite) veins. Same references as No. 2.

There are discrepancies between the 1866 account and that of 1871, as regards the nature of the samples analysed. Sample No. 2, according to the former account, represents the "boulder" freed from calcareous veins; sample No. 3, a second "boulder," similar in outward appearance to the first. (See also end of this chapter.)

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* Professor J. Park mentions this limestone in a letter dated 27th April, 1917.

Tertiary limestone is abundantly developed in the Oamaru district, and is of great importance both as a building-stone and as a source of lime. It is not clear whether all the limestone is in one geological horizon or not. The main body of limestone near Oamaru is known as the Oamaru stone. An upper band, separated from the Oamaru stone by a layer of volcanic tuff, is known as the Kakanui, Deborah, or Hutchinson Quarry limestone. In addition, the limestone near Ngapara and in the Waitaki Valley is considered by Park to belong to a higher horizon, and is called by him the Waitaki stone. McKay held a similar view, and called the limestone in question the Otakaika (Otekaieke) limestone. The Waitaki stone is generally not so pure as the Oamaru stone, and in places is arenaceous; hence Park calls it a calcareous sandstone. Analyses, however, show that it does not deserve this name, and is, on the contrary, a limestone which in many places is of high quality. The probability that all the limestone in the Oamaru district can be placed in one horizon seems very strong,* and if that be so, the existing accounts of the geology of this part of New Zealand can be considerably simplified.

A patch of Tertiary limestone occurs on the south bank of the Waitaki River above Kurow, near Wharekuri. It continues northward into Canterbury, as mentioned under Waimate County. According to McKay the limestone here is traceable for three miles, and is fully 50 ft. thick. Similar limestone occurs at Otekaieke itself, a few miles east of Kurow. It rests here on schistose or subschistose rocks (McKay, 1882 report, p. 66).

A few miles east of Otekaieke limestone occurs in the Maerewhenua Valley near Duntroon. This was called by McKay the Maerewhenua limestone, and was identified by him with the Ototara or Oamaru limestone (1882 report, pp. 69–70; see, however, pp. 103–4 also). "The Maerewhenua limestone, as a long line of cliffs 40 ft. to 60 ft. in height, bounds the Waitaki River for the first three miles below the Maerewhenua junction. Obscured by younger beds, it is present over a large area between the Kakanui and Maerewhenua rivers. North-west of the latter river it extends a distance of three miles, and terminates as a long line of cliffs." (McKay, 1882, p. 70.) Limestone covers large areas near Ngapara, where it is, however, not very thick. West of Ngapara the thickness on Mr. J. K. McCulloch's farm is about 30 ft.; elsewhere it may be a little greater. Various patches of limestone are seen south of the railway-line from Pukeuri to Papakaio, and a wide belt reaches from Division Hill to Deborah, and thence extends southward as a narrow strip to the Kakanui River near its mouth. Another strip of limestone extends for several miles north from Teschemaker's (Reidston). The exact position of numerous patches of limestone in the Oamaru district are shown by Park in his geological map of 1918, and therefore these need hardly be further mentioned. The same author fully describes many sections. He gives the thickness of the Waitaki stone as 6 ft. to 40 ft., of the Kakanui limestone as 2 ft. to 22 ft., and of the Oamaru stone as 20 ft. to 110 ft. (1918, p. 29).

The following analyses of limestones or calcareous rocks from Waitaki County were published in Geological Survey or Laboratory reports prior to 1908:—

	(1)	(2)	(3)	(4)	(5)
Carbonate of lime ..	91·17	67·08	58·72	27·11	64·10
Carbonate of magnesia ..	..	2·63	..	..	..
Iron oxides	..	0·90	..	..	..
Iron	..	..	..	34·29	8·42
Alumina	..	7·47	..	..	..
Siliceous matters ..	6·2	18·24	..	..	..
Water		3·68	..	..	..
	..	100·00	..	..	..

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* See Uttley, G. H.: "Geology of the Oamaru–Papakaio District." Trans. N.Z. Inst., vol. 50, 1918, pp. 118–24.

References.—(1) Chalk from railway-cutting (probably), Cave Valley (Waiareka district). McKay, Alex., in Rep. Geol. Explor., No. 14, 1882, p. 71. See also No. 10, 1877, p. 62, and No. 16, 1884, pp. 62–63.

(2) Rather loosely aggregated and somewhat incoherent calcareous stone from Waiareka Valley, forwarded by Mr. W. G. Blair. Col. Mus. and Lab. 19th Ann. Rep., 1885, pp. 26–27. Lab. No. 3789.

(3) to (5) From Kakanui, collected by Mr. Alex. McKay. Col. Mus. and Lab. 21st Ann. Rep., 1886, p. 37. Lab. Nos. 4241, 4286/*a*, 4286/*b*. On page 60 Lab. No. 4286 is attributed to Goodwood, Palmerston, but samples 4286/*a* and *b* no doubt came from the Kakanui River, for McKay has noted the presence of carbonate of iron in the Kakanui Valley, west of Cave Valley (1877 report, p. 63).

The following analyses represent samples from the neighbourhood of Oamaru :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Silica	2·03	3·05	0·97	..	14·16	15·73	3·85
Alumina	1·15	1·29	0·41	..	4·06	4·98	1·00
Ferric oxide	0·58	0·73	0·56	..	0·80	1·48	0·85
Lime	52·43	52·09	53·52	51·99	41·09	39·82	51·30
Magnesia	1·80	1·62	1·75	..	1·06	1·11	0·64
Carbon dioxide	41·20	40·93	42·05	40·85	32·29	31·29	40·30
Organic matter	0·81	0·29	0·74	..	5·66	4·74	1·86
Water							
Undetermined					0·88	0·85	0·20
	100·00	100·00	100·00	..	100·00	100·00	100·00
Calcium carbonate (per cent.)	93·63	93·02	95·57	92·84	73·38	71·11	91·60
Specific gravity	2·19	2·12	2·02	..	1·81	..	1·96
Water absorbed (per cent.) ..	10·05	12·16	19·27	..	15·01	..	11·65

References.—(1) to (3) Building-stones from Oamaru, forwarded by the Government Architect, Wellington. Dom. Lab. 41st Ann. Rep., 1908, p. 23. Lab. Nos. 1426/1-3. Lime and carbon dioxide calculated from calcium carbonate as given in the analyses. Water-absorption for period of 150 hours.

(4) From Totara district, forwarded by Reese Bros. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 330.

(5) to (7) Building-stones from Oamaru, forwarded by the Government Architect, Wellington. Dom. Lab. 46th Ann. Rep., 1913, p. 19. Lab. Nos. C 264/1–3. Water-absorption for period of sixty hours. Fine-grained greenish portions of No. C 264/1 contained only 35·6 per cent. of calcium carbonate.

The following analyses, also representing samples from the Oamaru district, need to be tabulated somewhat differently :—

	(1)	(2)	(3)	(4)	(5)
Matter insoluble in acid	1·93	2·15	1·15	1·40	1·19
Alumina and iron oxide	0·30	0·30	2·03	0·50	0·94
Calcium carbonate	94·82	95·64	96·06	97·63	96·95
Magnesium carbonate	1·54	1·60	0·76	0·47	0·92
Water, organic matter, &c.	1·41	0·31			
	100·00	100·00	100·00	100·00	100·00
Specific gravity	1·54	1·74	..	..	..
Water absorbed in 120 hours (per cent.)	19·65	14·17	..	..	..
Quicklime in calcined stone (per cent.)	94·7	94·4	93	96	95

References.—(1) (2) Fine-grained even limestone from the Oamaru T. T. & C. Stone Company. Dom. Lab 47th Ann. Rep., 1914, p. 19. Lab. Nos. D 478/1, 2. Total iron oxide, 0·72 and 0·46 per cent. respectively.

(3) From Oamaru, forwarded by Director, Fields Division (Agricultural Department). Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 1022.

(4) (5) From Totara, forwarded by S. H. Shale. Dom. Lab. 48th Ann. Rep., 1915, p. 20. Lab. Nos. E 793/1, 2.

The following analyses represent samples collected by Professor James Park, by one of the writers, and by Mr. J. K. McCulloch (by request) on different occasions :—

	(1)	(2)	(3)	(4)	(5)	(6)
Silica, or matter insoluble in acid	2·75	3·86	6·10	14·25	3·00	16·92
Alumina (Al_2O_3)	0·51	0·81	..	..	..	..
Iron oxide (Fe_2O_3)	0·69					
Lime (CaO)	52·58	51·05	50·68	42·60	53·82	41·44
Magnesia (MgO)	0·48	0·45	..	..	..	..
Carbonic anhydride (CO_2) ..	41·84	35·47	39·22	33·00	41·97	31·16
Phosphoric anhydride (P_2O_5) ..	..	3·63	0·19	0·74	0·07	1·62
Moisture, organic matter, &c. ..	1·15	1·73	3·48	3·44	0·71	2·95
	100·00	97·00	99·67	94·03	99·57	94·09

	(7)	(8)	(9)	(10)	(11)
Silica, or matter insoluble in acid ..	0·51	2·83	12·86	1·97	0·99
Alumina (Al_2O_3)	1·33	3·10	1·37	1·25	1·41
Iron oxide (Fe_2O_3)	1·20	1·92	1·81		
Lime (CaO)	53·85	49·98	41·34	53·61	53·52
Magnesia (MgO)	0·40	1·21	1·59	0·63	1·06
Carbonic anhydride (CO_2)	41·40	39·08	30·80	42·40	42·32
Phosphoric anhydride (P_2O_5)	..	..	..	..	..
Moisture, organic matter, &c.	1·07	1·47	8·42	0·46	0·66
	99·76	99·59	98·19	100·32	99·96

References.—(1) Oamaru stone from Totara Quarry, forwarded by Professor James Park. Col. Lab. 38th Ann. Rep., 1905, p. 11 ; and Trans. N.Z. Inst., vol. 37, 1905, p. 544. Lab. No. 9864/5.

(2) Rather soft, nearly white, phosphatic limestone from Mr. J. K. McCulloch's property (near homestead) west of Ngapara ; collected by P. G. Morgan in May, 1915. Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. No. F 608.

(3) Rather soft limestone from two localities on Mr. J. K. McCulloch's farm.

(4) Glauconitic arenaceous limestone (shelly) underlying No. 3.

(5) Hard crystalline limestone (ordinary limestone of district).

(6) Hard, arenaceous, highly glauconitic limestone below Nos. 3, 4, and 5, containing numerous fragments of bone. The sample contains 1·22 per cent. of potash (K_2O). The four samples Nos. 3 to 6 were forwarded to the Geological Survey in August, 1915, by Mr. J. K. McCulloch, and are from the neighbourhood of his homestead west of Ngapara. Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. Nos. F 886/1–4.

(7) Limestone from Meek's quarry, Teaneraki.

(8) Hutchinson Quarry limestone, Oamaru.

(9) Arenaceous limestone (Waitaki stone), Duntroon.

(10) High-grade limestone (Waitaki stone), Duntroon.

(11) Limestone from Flat-top Hill, near Kakanui.

Analyses Nos. 7 to 11 represent samples collected by Professor Park, and are given in N.Z. Geol. Surv. Bull. No. 20, 1918, p. 115. (See also Dom. Lab. 50th Ann. Rep., 1917, p. 20.) Lab. Nos. G 264/1, 2, 3, 4, 6.

In May, 1908, one of the writers collected a number of samples of limestone near Oamaru in order that their phosphate content might be ascertained. The results obtained need not be quoted in full, none of the localities being of any importance as a source of lime. The calcium-carbonate contents were as follow :—

Sample.	Locality.	Calcium-carbonate Percentage.	Analysed by
A	Hutchinson's Quarry	80·7	D. B. Waters.
B	"	92·5	"
C	Vein-like band in volcanic rock near Gardens	75·0	"
F 595/1	Ditto	89·68	Dominion Laboratory.
F 595/2	Hutchinson's Quarry	93·25	"
F 595/3	"	94·32	"
F 595/3A	"	92·62	"
F 595/4	"	85·90	"
F 595/5	Vein-like band in volcanic rock near Breakwater	95·12	"
F 595/6	Ditto	66·28	"
F 595/7	"	92·59	"
F 595/8	"	89·50	"

Sample F 595/6 contained 12·28 per cent. of magnesia (MgO), equivalent to 25·79 per cent. of magnesium carbonate ($MgCO_3$).

B. C. Aston gives the following analysis of limestone from the Shag Point district. The locality may be either in Waitaki or Waihemo County.

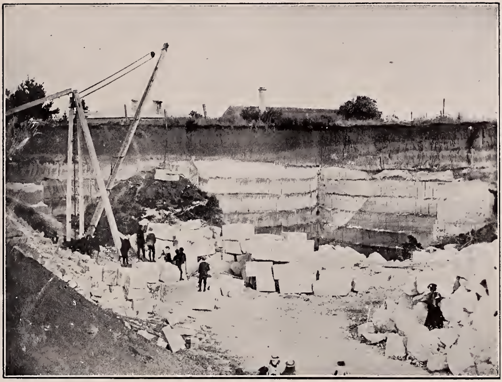
Silica and matter insoluble in acid	37·4
Alumina and iron oxides	6·7
Lime	26·8
Magnesia	1·8
Carbonic anhydride	22·9
Phosphoric anhydride	0·8
Organic matter and water	3·1
Alkalies and loss	0·5
	100·0

Reference.—Supposed coprolite, but actually an impure limestone (? a concretion), forwarded by Mr. John Hodson. Dept. Agric. 8th Ann. Rep., Chem. Division, 1900, p. 4. Analyst's No. 2.

In "Reports and Awards of the Jurors, N.Z. Exhibition, 1865" (Wellington, 1866), page 448, Hector and Skey give five analyses of limestones from the Oamaru district. These are quoted in full with other analyses in an appendix at the end of this chapter. The samples and their carbonate-of-lime content were as follow :—

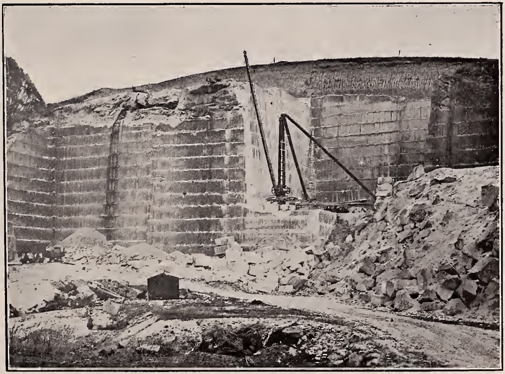
Analyst's Number.	Locality.	Description.	Calcium-carbonate Percentage.
4	Hutchinson's Quarry	Compact, fossiliferous ..	95·95
6	"	Lithographic (fine-grained) ..	95·18
10	"	Granular, compact	93·42
16	Oamaru district	White, granular	90·14
17	3½ miles south of Oamaru ..	Conglomeratic, hard, compact	87·08

In "Official Record of the N.Z. and South Seas Exhibition, 1889–90" (Wellington, 1891), J. G. Black (pp. 368, 369, 370, 371) gives analyses of twelve samples of Oamaru



A. Quarry of Oamaru Stone, Teschemaker's, Waitaki County.

[From Geol. Surv. Bull. No. 20. Photo by A. C. Gifford.]



B. Gay's Oamaru Stone-quarry, near Weston, Waitaki County.

In above views the horizontal lines are not due to bedding, but have been produced during quarrying. The smooth portions of the faces are saw-cuts.

[From Geol. Surv. Bull. No. 20. Photo by James Park.]

stone, three of which are from Kakanui. In view of the numerous analyses of Oamaru stone already quoted, the following tabulation of the chief particulars may be deemed sufficient :—

Analyst's Number.	Locality.	Exhibitor.	Calcium-carbonate Percentage.	Specific Gravity.	Remarks.
6	Oamaru ..	Robertson and Kelly ..	89·0	1·76	Medium coarse-grained.
6A	,, ..	,, ..	90·0	1·76	
8	,, ..	,, ..	90·0	1·65	Hard, fairly cemented.
12	Kakanui ..	G. Munro	95·0	1·33	
12A	,, ..	,, ...	95·0	1·33	
26	Oamaru ..	T.T. Company ..	97·0	1·53	Medium coarse-grained.
31	,, ..	Built in First Church..	97·0	1·51	
32	,, ..	Robertson	94·0	1·53	Hard, fairly cemented.
33	,, ..	C. and B.	83·7	1·73	Fine-grained, fairly cemented; sand and clay high.
35	,, ..	,, ...	84·0	1·73	
39	Kakanui ..	G. Munro	90·7	1·65	Porous, poorly cemented.
40	Oamaru ..	Built in First Church ..	93·4	1·46	..

W. N. Blair, in " The Building Materials of Otago and South New Zealand generally " (Dunedin, 1879), describes the Oamaru stone on pages 33–44, 101, 102, 103, 105, and 109. He also quotes the following analysis of a yellow fossiliferous compact hard limestone from Kakanui, made by Dr. J. G. Black for Mr. Cairns :—

Carbonate of lime, and lime (as silicate)	97·0
Carbonate of magnesia	1·0
Insoluble sand	1·5
Alkalies, water, and loss	0·5
	100·0

Reference.—Blair, W.N., 1879, p. 101, and No. 11, Table I. Under " Remarks " a reference is given to " Laboratory Report, 1875–76."

Limestone, probably of Mesozoic age, is reported to occur at or near Dansey's Pass, west of Livingstone.

Summary of Limestone Resources, &c.

Waitaki County contains great quantities of high-grade limestone, favourably situated for being worked ; yet even in this county, which is so well known, so long settled, and so much visited by geologists, there is scope for further exploration and sampling of the deposits. When freshly broken the Oamaru limestone is so friable that it cannot conveniently be calcined in a kiln of the ordinary type. It could, however, on account of its softness, be coarsely pulverized at a very low cost. Probably also it could be successfully calcined in a revolving-cylinder furnace. Park remarks that " valuable deposits of hard limestone suitable for burning for lime for agricultural purposes occur at Flat-top Hill and Teaneraki. The deposits at Kakanui, Deborah, and Hutchinson's Quarry are practically exhausted." With regard to the last-named locality it may be said that the original deposit was almost negligible. Here, however, lime was first made in Otago by Mr. D. Hutchinson, probably quite sixty years ago.* The lime was shipped to Dunedin for building purposes, but after a time Mr. Hutchinson, it is said, shipped the limestone instead, and it was burned in a kiln erected at North-east Valley, where wood was then abundant.

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* See, however, reference to an old lime-kiln in Kaikorai Valley, on p. 274 of this bulletin.

Much of the limestone in the Ngapara district is suitable for kiln calcination, and good quarry-sites are numerous. It is likely that equally good limestone occurs at many other places—for example, in the Waitaki Valley at Duntroon, Otekaieke, and Wharekuri—but these localities have not been seen by the writers.

Better opportunities for the erection of large lime-works exist in the Oamaru district than in almost any other part of the South Island. The limestone is of high grade, can be cheaply quarried, and in many places is close to a railway.

Means of Transport.

Waitaki County has the partly artificial harbour of Oamaru, defended by a breakwater which at present is of insufficient length to allow the port to be used by Home liners. The coastal part is traversed by the Dunedin–Christchurch Railway, from which branch railways run to Tokarahi (with sub-branch to Ngapara) and Kurow. The settled portions of the county are well roaded. The main inland road is from Kurow to the Ahuriri Plain (part of the Upper Waitaki Plain), where it joins the coach and motor road from Pukaki to Lake Hawea, &c.

Literature.

The Oamaru district has been much visited by geologists. An area of about 137 square miles has been geologically surveyed in detail, and the results are embodied in N.Z. Geol. Bull. No. 20, 1918, "The Geology of the Oamaru District, North Otago (Eastern Otago Division)," by James Park. The early geological literature is quoted and summarized on pages 4 to 7, and is followed by a list of geological papers and reports published since 1877. To this bulletin the reader is therefore referred for full information. The following reports and papers mostly either refer to localities outside the Oamaru district, or have been quoted (directly or indirectly) on the preceding pages:—

Rep. Geol. Explor., No. 10, 1877, part of pp. 41–66 (with map); No. 14, 1882, part of pp. 56–92 (with map), 98–106; No. 16, 1884, pp. 45–66 (with map); No. 21, 1892, pp. 172–74.

Part of Parl. Paper C.-4, 1894 (bound with Mines Rep.), pp. 31, 38–39, &c. (with map).

Trans. N.Z. Inst., vol. 34, 1902, pp. 447–51 (A. Hamilton); vol. 36, 1904, pp. 447–53 (Park, on Mount St. Mary rocks), 465–67 (A. Hamilton); vol. 50, 1918, pp. 106–17 (G. H. Uttley), 118–24 (Uttley).

"Geology of Canterbury and Westland," 1879, pp. 46, 57, part of pp. 199–205, &c.

39. LAKE COUNTY.

Lake is a highly mountainous county, comprising a large area in north-west Otago. Palæozoic schists, argillites, and greywackes occur over the greater part of the county. These are in places intruded by granite and other igneous rocks. Old Mesozoic rocks are probably also present. Tertiary rocks occur as patches in various localities, and at Martin's Bay, Bob's Cove (Lake Wakatipu), and elsewhere contain limestone. The Quaternary rocks are mainly fluviatile and glacial gravels. They include, however, some highly calcareous marls, formed in fresh-water lakes.

According to Marshall (Trans. N.Z. Inst., vol. 39, 1907, p. 503), the harzburgite of Anita Bay, Milford Sound, in places tends to pass into a marble (magnesite). Speight found veins of what he calls "marble passing into harzburgite in a dark indistinctly foliated rock at the western point of the bay" (1910, p. 269). This marble is probably magnesite, but no analysis is given. Donald Sutherland found blocks of marble in the valley on the south side of Mitre Peak (Trans. N.Z. Inst., vol. 16, 1884, p. 455), in a valley south of Fox Point, and in a valley draining into Poison Bay (p. 456). Hutton mentions that cipollino (a granular, coarsely crystalline limestone or marble containing "numerous flakes of lithia-mica") occurs at Anita Bay ("Geology of Otago," 1875, p. 27).

McKay states that heavy (thick) beds of grey subcrystalline limestone appear on the western slopes of the Lake Harris Range, and also farther north in the Bryneira or Barrier Range (1881 report, p. 142). According to Park (1887 report, p. 132) the limestone thins out to the north of these mountains, but in a section across them it is not less than 2,000 ft. thick (including interbedded layers of "aphanite sandstone").

The following analysis perhaps represents a sample from the Palæozoic rocks of Lake County, but may refer to the Bob's Cove limestone. It is described as a marble that occurs at Wakatipu.

Carbonate of lime	96·81
Carbonate of magnesia	2·06
Alumina	0·90
Iron oxide	Traces
Silica (? matter insoluble in acid)	0·21
Water	0·02
	100·00

Reference.—Forwarded by Mr. J. W. Eliott. Col. Mus. and Lab. 18th Ann. Rep., 1883, pp. 44, 46. Lab. No. 3438.

As mentioned under Westland County, small patches of Tertiary rocks occur at the north and south headlands of Big Bay. They are calcareous in their upper layers, whilst the conglomerate at the base contains large blocks of argillaceous limestone. Above the conglomerate is argillaceous limestone interbedded with sandstone (Park, 1887, p. 131).

At the south head of Martin's Bay 40 ft. of cream-coloured limestone, apparently of excellent quality, rests on schist (unconformably). Overlying the limestone is conglomerate, and this is succeeded by several hundred feet of calcareous shale (Hector, 1863, p. 465).

At Bob's Cove, near Twelve-mile or Few's Creek, Lake Wakatipu, there is a band of Tertiary limestone 75 ft. thick, of which 50 ft. consists of high-grade stone. The bed of limestone can be traced on the surface for 40 chains, and rises in that distance to a height of over 1,600 ft. above the lake. It can be easily and economically worked. Park estimates that 2,500,000 tons can be excavated above water-level, without the removal of much overburden (1909, p. 99). The limestone is pale-yellowish-grey to drab in colour, close in texture, semi-crystalline in structure, and very hard. It is "suitable for burning for lime for mortar and agricultural purposes, and for the manufacture of cement. It possesses all the characteristics of a first-class building-stone, including strength, durability, and good colour, and, having a fine texture, is easily worked, and takes a fine polish" (Park, 1909, p. 99). In 1879 the stone was being quarried and burnt in a kiln (Cox, 1879, p. 53). In 1909 the lime-kiln was still in existence, but the writers do not know whether it was then being worked or not.

Analyses of Bob's Cove limestone are—

	(1)	(2)	(3)
Calcium carbonate	91·60	90·5	92·42
Magnesium carbonate	2·94	3·0	..
Alumina and iron oxide	0·84	..	3·60
Silica and insoluble matter	4·62	..	4·03
	100·00	..	100·05

References.—(1) Hard compact grey limestone from Lake Wakatipu. Hector and Skey, 1886, as previously cited, pp. 393, 448. See also appendix to this chapter.
(2) Hutton, F. W., "Geology of Otago," 1875, p. 48.
(3) Park, J., N.Z. Geol. Surv. Bull. No. 7, 1909, p. 99. Analyst, Mr. G. M. Thomson, F.L.S.

The Bob's Cove limestone is overlain by sandstones and conglomerates, and underlain by marly and clayey sandstones, marly clays, and calcareous breccia conglomerate. These beds near the lake strike a little east of true north, and dip westward at an angle of 55°. At 15 chains (more or less) from the lake they bend sharply to the west for perhaps 20 chains, and then bend as sharply to the north again. A few chains to the north the outcrops abruptly cease at a cliff facing north. Their continuation is hidden by Pleistocene gravels. The following figure (after Park) shows a section through the east-and-west striking portion of the beds:—

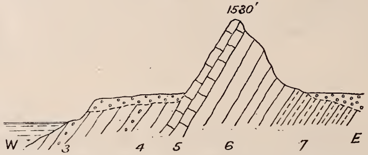


Fig 7.—Section across Limestone Ridge east of Bob's Cove, Lake Wakatipu.

3. Sandstones and conglomerates. 4. Sandstones. 5. Limestone. 6. Marly sandstone. 7. Marls and marly clays.

Note.—For W in above figure read S, and for E read N.

The marly clay (No. 7) shown in the above section is approximately 600 ft. thick. "It is simply a hardened sea-mud, having the following composition:—

[Analysis by Mr. G. M. Thomson, F.L.S.]

"Calcium carbonate	34·52
Calcium oxide (not combined as carbonate)	2·39
Alumina and oxide of iron	6·50
Magnesia	0·72
Silica and insoluble matter	51·60
Alkalies and loss	2·51
Moisture	1·76
	100·00

"The marl and limestone are admirably adapted for the manufacture of cement. Both occur close to deep water, both exist in immense quantity, and there is a sufficient supply of water in the Twelve-mile Creek near-by to provide all the motive power required in the manufacture. The only disability that exists is the absence of a known coal-deposit in the vicinity." (Park, 1909, p. 100.) Another disability is the absence of a sufficient population on or near the shores of Lake Wakatipu to utilize a large production of cement. A well-inhabited district, however, is served by the railway south from Kingston, and in time the erection of cement-works may be commercially feasible.

A very narrow band of fault-involved Tertiary breccia conglomerate extends northward from a point somewhat to the east of the beds described above. It is seen west of Moke Lake, in the Moonlight Creek, in Stony Creek, on Silverhorn, and north of Mount Aurum, where it seems to end. The total length of this extraordinary band is about twenty-four miles. In many places it is highly calcareous, but can be of no importance as a source of lime.

An interesting and important deposit of marl occurs at the south end of Lake Hayes, about four miles east-north-east of Kawarau Falls, and has been fully described by Park (1909, pp. 97–99, &c.). It consists of finely bedded grey bands of highly calcareous material, interbedded with drab-coloured layers of less pure material. These beds now form a fairly high terrace facing the lake, but were evidently formed in the lake when it stood at a higher level. Park thinks that it was precipitated from the waters of the lake by the action of mosses and fresh-water algæ. "The material is excessively fine in texture, and so soft as to be easily excavated by a spade without exerting much force. Its purity and pulverulent form render it of great economic value for agricultural purposes, both for dressing the land and in the manufacture of manures. Already several hundred tons of it have been bagged and forwarded to Southland." At the south-west and south-east corners of the lake the highly calcareous bands are thicker and purer than elsewhere. In the former locality Park's section shows surface soil underlain by 4 ft. of soft limestone or calcareous ooze, below which is 6 in. to 12 in. of drab-coloured silt, 6 ft. of soft limestone of good quality, and 16 ft. of impure limestone. It was being worked here by Reid and McDowell in 1909. At the south-east corner of the lake the surface soil is underlain by 6 ft. 6 in. of soft limestone (good quality), 2 ft. to 3 ft. of drab-coloured silt, 3 ft. 6 in. of good limestone, 6 ft. of impure limestone, and drab-coloured silt. Park says, "The extent of the deposits at the places described above is not known, and can only be determined by boring or sinking shafts on the terrace. If the thickness as exposed in the present working-faces be maintained, it is estimated that each acre should contain 12,000 to 15,000 tons of limestone of marketable quality, and 10,000 tons of impure limestone suitable for top-dressing agricultural and pastoral lands that are deficient in lime." (1909, pp. 98–99).

The following analyses are quoted by Park (p. 99). They were presumably made on air-dried samples.

	(1)	(2)	(3)	(4)	(5)
Silica	7·15	41·90	10·78	6·30	10·54
Alumina	3·24	18·50	5·12	2·61	4·28
Ferric oxide	2·00	7·68	2·40	1·76	2·12
Manganous oxide	0·07	0·25	0·05	0·05	0·12
Lime	47·70	12·52	44·25	48·44	45·30
Magnesia	0·20	2·57	0·40	0·25	0·30
Carbonic anhydride*	36·90	8·32	34·43	37·85	34·80
Moisture and organic matter	1·77	3·72	1·03	1·57	1·61
Undetermined	0·97	4·54	1·54	1·17	0·93
	100·00	100·00	100·00	100·00	100·00
*Equivalent to calcium carbonate	83·86	18·91	78·25	86·02	79·09

References.—(1) Top layer, south-east side of Reid and McDowell's quarry.

(2) Grey band (middle layer; drab-coloured silt).

(3) Lower band of soft limestone, 6 ft.

(4) Impure limestone at base. (Note, however, that the analysis shows this to be the best sample of all).

(5) Average sample of whole face.

The analyses are also given in Dom. Lab. 42nd Ann. Rep., 1909, p. 20. Lab. Nos. 1570/1–5.

Of the following four analyses, the first two refer to the Lake Hayes calcareous ooze, the third (near Frankton) no doubt also represents the same deposit, but the fourth (Gibbston) probably represents one of the scattered ice-borne boulders of limestone that occur in the Lake Wakatipu district. As a matter of fact, a large mass of greyish-white crystalline limestone occurs at the upper end of Gibbston Flat (Park, N.Z. Geol. Surv. Bull. No. 5, 1908, p. 34).

	(1)	(2)	(3)	(4)
Silica	7·95	8·17	36·85	..
Alumina and iron oxides	0·80	2·50	7·80	..
Lime	47·78	44·90	26·57	(53·31)
Magnesia	..	1·19	0·90	..
Carbonic anhydride	..	..	20·90	(41·88)
Loss on ignition (mainly CO_2)	37·83	37·72	..	..
Moisture, &c.	5·64	6·32	5·85	..
	100·00	100·80	98·87	..
Calcium carbonate as given by analysts (per cent.)	84·32	80·17	47·40	95·19
Calcium carbonate equivalent to lime present (per cent.)	85.32	80·18	47·45	95·19

References.—(1) (2) Aston, B. C.: Dept. Agric. 16th Ann. Rep., Chemistry Division, 1908, p. 286. Analyst's Nos. J 323, 324.

(3) Near Frankton, forwarded by Mr. John Duncan, M.P. Dom. Lab. 44th Ann. Rep., 1911, p. 15. Lab. No. A 987.

(4) From Gibbston, forwarded by Mr. D. Hodson. Aston, B. C.: Dept. Agric. 12th Ann. Rep., 1904, p. 143. Analyst's No. E 166.

Highly calcareous marl, somewhat, but apparently not altogether, similar to the Lake Hayes calcareous ooze, occurs near the south end of Lake Wanaka in the Cardrona Valley. In 1881 McKay examined some low hills (or mounds) at the foot of Roy's Peak which were entirely composed of marl. The space covered by the deposit he estimated at 5 or 6 chains in length by 3 chains in breadth, with a thickness not exceeding 30 ft. The deposit was stratified, and rested horizontally on the underlying rock (? schist). Examined under the microscope the marl was seen to consist "mainly of the broken shells of fresh-water molluscs, with a small proportion of diatomaceous organisms" (1882 report, p. 60). An analysis of the calcareous marl seen by McKay is given below:—

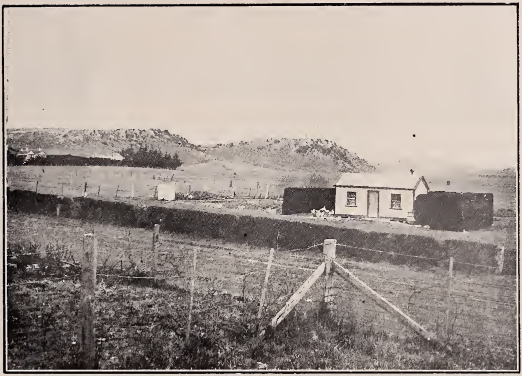
Carbonate of lime	91·60
Carbonate of magnesia	2·49
Alumina and iron oxide	0·62
Siliceous matter	2·94
Water	2·35
	100·00

Reference.—Rep. of Geol. Explor., No. 14, 1882, p. 60.

The following analyses of friable limestone from the west side of Lake Wanaka perhaps represent samples of highly calcareous marl similar to that mentioned above:—

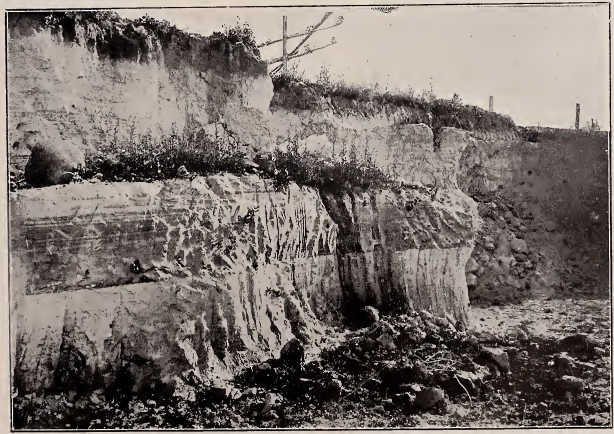
	(1)	(2)
Silica (SiO_2)	4·15	1·38
Alumina and iron oxides (Al_2O_3, FeO, and Fe_2O_3)	1·23	0·59
Lime (CaO)	51·64	52·46
Magnesia (MgO)	0·79	0·73
Carbonic anhydride (CO_2)	39·42	40·57
Moisture and organic matter	2·62	4·14
Phosphoric anhydride (P_2O_5)	0·15	0·13
	100·00	100·00
Calcium carbonate ($CaCO_3$) equivalent to lime (per cent)	92·21	93·68
Lime (CaO) in calcined stone (per cent.)	89·1	94·9

Reference.—Forwarded by Mr. P. R. Sargood. Dom. Lab. 47th Ann. Rep., 1914, p. 21. Lab. Nos. D 21/1, 2.



A. Escarpment of Oamaru Stone running Seaward from Totara, Waitaki County.

From Geol. Surv. Bull. No. 20. Photo by James Park.]



B. Quarry of Calcareous Ooze, South-east End of Lake Hayes, Lake County.

[*Photo by James Park.*]

Summary of Limestone Resources, &c.

Lake County, as will be seen from the preceding pages, is not without limestone resources. The limestone near Bob's Cove may either be calcined, or ground with the aid of water-power supplied by the neighbouring Twelve-mile Creek, and then distributed round Lake Wakatipu. It might also supply a considerable area south of Kingston, where, however, it would enter into competition with lime from the Winton and Limehills districts. The calcareous ooze or marl of Lake Hayes is close to Frankton Flat and the well-known Crown Terrace, both of which, especially the latter, are good agricultural areas. The similar material in the Cardrona Valley near Lake Wanaka is also well situated for supplying neighbouring agricultural land, and is not far from the Hawea Flats. The Lake Harris and Bryneira ranges contain a great amount of limestone, but this cannot be utilized in any way at the present time. The limestone at Martin's Bay may possibly be locally used at some future time. It is advisable to explore, map, and sample the calcareous marl of the Cardrona Valley. Other deposits besides those known may be discovered. The limestone near Bob's Cove needs further and systematic sampling, one or two analyses of hand-specimens being of little use, if the erection of large lime or cement works is contemplated.

Means of Transport.

In Milford Sound Lake County possesses a magnificent harbour which at the present time is quite valueless as a means of communication or transport. The so-called Sutherland Sound, a few miles to the south, is a salt-water lake, entered by a narrow channel (2 chains in width) having, it is said, a depth of 3 fathoms on the bar at its entrance (Trans. N.Z. Inst., vol. 16, 1884, pp. 454–58). Lake McKerrow is an almost similar body of water, having its entrance north of Martin's Bay. The latter bay and Big Bay afford some shelter for shipping. Lakes Wakatipu and Wanaka afford some scope for inland navigation. A railway-line from Kingston, at the south end of Lake Wakatipu, runs almost due south to Invercargill, but only a few miles are in Lake County. The roads of the county are found almost entirely in its eastern part. A fairly good system (regard being given to the mountainous nature of the country) links up Queenstown with Arrowtown, Skipper's, Pembroke, and Cromwell (in Vincent County). Kingston is connected with Invercargill by road, and a few miles of road have been made in the Von Valley and near Glenorchy (at the head of Lake Wakatipu). Many attempts to find a practicable route to Milford Sound have been made, but up to the present these have all failed.*

Literature.

Part of Lake County has been geologically surveyed in detail by Professor James Park, and the results of his work will be found in the following two bulletins, the latter of which deals with an area wholly in Lake County, the former with an area only part of which is in the county :—

N.Z. Geol. Surv. Bull. No. 5, "The Geology of the Cromwell Subdivision, Central Otago Division," 1908 ; N.Z. Geol. Surv. Bull. No. 7, "The Geology of the Queenstown Subdivision, Western Otago Division," 1909.

These bulletins contain full lists of the literature dealing with Lake County. The following publications may here be cited either as supplementary to Park's lists, or as being of special interest, or on account of their being quoted above :—

Hector, J. : Geol. Exped. to the West Coast of Otago, *Otago Prov. Gazette*, 5th Nov., 1863, pp. 435–78. (See especially pp. 435–39, 460–68.)

Hutton, F. W. : "Geology of Otago," 1875.

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* A possible but not an easy route was discovered by Messrs. W. G. Grave and H. Talbot a few years ago.

Rep. of Geol. Explor., No. 4, 1868, pp. 42–44 (Hector); No. 12, 1879, pp. 53–55 (Cox); No. 13, 1881, pp. xxvii–xxx, 118–47 (McKay); No. 14, 1882, parts of pp. xi–xiii, 56–92 (McKay); No. 16, 1884, parts of pp. xxii–xxv, 45–66 (McKay), 76–81 (McKay); No. 18, 1887, pp. xlvi–xlix, 121–37 (Park); No. 21, 1892, pp. xli–xlix, 23–24, 157.

Parl. Paper C.–4, 1894, pp. 12–17, part of 32–48, &c. (McKay); bound in Mines Rep.; 2nd ed., 1897. Parl. Paper C.–6, 1894, part of pp. 7–9; bound in Mines Rep.

Trans. N.Z. Inst., vol. 16, 1884, pp. 454–58 (Donald Sutherland); vol. 28, 1896, p. 724 (Sutherland); vol. 37, 1905, pp. 481–84 (Marshall); vol. 38, 1906, pp. 560–67 (Marshall); vol. 39, 1907, part of pp. 396–403 (Marshall); vol. 41, 1909, part of pp. 64–84 (A. M. Finlayson); vol. 42, 1910, part of pp. 255–67 (Speight).

Ulrich, G. H. F., in Quart. Jour. Geol. Soc., vol. 46, 1890, pp. 619–32, deals with awaruite (see also Westland County) and the geology of an area south of Cascade Point, part of which is in Lake County.

40. Vincent County.

Vincent County, which lies immediately east of Lake County, is a mountainous tract of considerable extent. Its most characteristic rocks are mica-schists and allied metamorphic rocks which are almost certainly of Palæozoic age, though believed by Marshall to be old Mesozoic. In the extreme north-east argillites and greywackes of younger age than the schists appear. The county contains several large intermontane depressions* or so-called lake-basins. One of these is almost entirely filled to this day by Lake Wanaka, and another is partly occupied by Lake Hawea. The origin of these depressions has been discussed by several geologists, and it is now agreed that they have been formed mainly through extensive block-faulting and tilting, a mode of origin that applies in a general way to all large intermontane basins in the South Island. The latest and probably most satisfactory explanation of their mode of origin has been given by C. A. Cotton (1917—see literature listed on p. 266). In various places on the margins of the basins are found Tertiary lignites, conglomerates, sands, and clays, usually strongly involved in faults. Some volcanic rocks are associated with these beds. The youngest rocks of Vincent County are the fluviatile and morainic gravels that cover the valley and basin floors.

A vein of white marble is said to occur on the eastern bank of the Clutha or Molyneux River between Clyde and Cromwell (Blair, W. N.: "The Building Materials of Otago," 1879, p. 26).

In places the Tertiary strata, which to some extent are certainly lacustrine, contain, according to McKay, marly beds and occasional layers of hard stone, which may contain as much as 60 per cent. of lime (1884 report, p. 64). No evidence of marine strata of Tertiary age has been obtained in Vincent County, but probably beds of this character once existed over at least part of the county.

No record of Recent or Pleistocene lake marl similar to that of Lake Hayes and the Cardrona Valley has been made, but probably such deposits exist. Recently a calcareous powder from Geordie's Hill, Lindis Valley, has been analysed in the Dominion Laboratory, with the following results: Insoluble in acid, 4·42 per cent.; calcium carbonate, 94·02 per cent.; water lost at 100° C., 0·22 per cent. The material, which was collected on Mr. James Goodger's land, very likely consists of calcareous marl similar to that found on the west side of Lake Wanaka.

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* On p. 241 the use of the term "depression" for a basin where subsidence was not proved was deprecated, but in the case of the Otago basins it can hardly be avoided. C. A. Cotton uses the term freely and without comment in his article of 1917.

The following analysis of "sandstone from Manuherikia" perhaps represents a marl from the Tertiary lacustrine deposits (compare with analyses of the Lake Hayes calcareous ooze, pp. 261, 262):—

Carbonate of lime	60·74
Carbonate of magnesia	2·08
Iron and alumina soluble in acid	1·60
Water	3·19
Siliceous matter (clay, &c.)	32·39
	100·00

Reference.—Collected by Mr. Alex. McKay. Col. Mus. and Lab. 18th Ann. Rep., 1883, p. 45. Lab. No. probably 3453 (p. 66).

The rock is described as a "sandstone" by Skey, and sample No. 3453 is called a "siliceous rock"; but since the "siliceous matter" was mainly clay, as Skey expressly remarks, the specimen analysed must represent a marl, which would be of considerable value for agricultural purposes.

In "Reports and Awards of the Jurors, N.Z. Exhibition, 1865" (Dunedin, 1886), p. 392, Hector and Skey mention that some very fine specimens of travertine limestone from the Dunstan Gorge were exhibited. The rock was exceedingly porous, and coloured in parts yellow, especially on exposed surfaces, but burnt to a beautifully white lime. The following analysis is given (p. 448):—

Carbonate of lime	95·04
Carbonate of magnesia	2·56
Alumina	0·60
Soluble silica	Trace
Insoluble matter	1·80
	100·00

Colour, grey and yellow. Analyst's No. 7. Exhibition No. 737 (Geological Survey of Otago). (See also appendix to this chapter.)

Park's geological map of Bannockburn Survey District (N.Z. Geol. Surv. Bull. No. 5, 1908, opposite p. 58) shows a deposit of travertine extending for over a mile up a small eastern branch of Bannockburn Creek. The locality is four or five miles east of south from Bannockburn Township. A mile to the north another deposit of smaller size is shown on the east side of Bannockburn Creek. Unfortunately, no information concerning these deposits is given in the text of Bulletin No. 5. It may be surmised that the sample analysed by Skey came from one of them, but according to W. N. Blair (as previously cited, 1879, p. 102) travertine is found in [some of] the small creeks that flow into the Clutha and Kawarau rivers between Roxburgh and the Shotover. The stone was first burned for lime in 1864, and mortar made from this lime was used in the masonry of the Gentle Annie Bridge and of many houses in the Clutha Valley.

Summary of Limestone Resources and of Means of Transport.

Vincent County can hardly be said to have any limestone resources other than the travertine deposits mentioned above. Some search for marl deposits either of Tertiary or modern age is advisable. Such lime as the county needs will apparently have to be obtained mainly by rail from Milburn, in Bruce County, but the hauling-distances will be great. Some lime may perhaps be obtained from the limestone near Bob's Cove, Lake Wakatipu, and from the marl near Pembroke, Lake Wanaka. The extension of the Dunback Railway to Ranfurly (see also Maniototo County) would much improve the facilities for the importation of lime. A railway-line branching from the Dunedin–Invercargill Railway at Wingatui enters Vincent County west of Ida Valley, and continues through Alexandra and Clyde to Cromwell, the portion beyond Clyde, however, being of light construction only. If regard be given to its mountainous nature and somewhat scanty population, Vincent County must be considered fairly well roaded. Lakes Hawea and Wanaka afford a certain amount of internal navigation.

Literature.

Part of Vincent County has been geologically surveyed in detail by Professor James Park. The results of his work are embodied in N.Z. Geol. Surv. bulletins Nos. 2 and 5, the full titles of which are "The Geology of the Area covered by the Alexandra Sheet, Central Otago Division," 1906, and "The Geology of the Cromwell Subdivision, Western Otago Division," 1908. The lists of literature in these bulletins include nearly all the publications dealing with the geology of Vincent County. The following abbreviated list gives all of importance for the objects of the present bulletin, and a few supplementary papers are also mentioned:—

Hutton, F. W.: "Geology of Otago," 1875.

Haast, Julius von: "Geology of Canterbury and Westland," 1879, pp. 46, 47, 48–49, 56–57, 254–55, &c.

Rep. of Geol. Explor., No. 14, 1882, parts of pp. xxi–xxiii, 56–92 (McKay); No. 15, 1883, pp. xx, 80–83 (McKay); No. 16, 1884, parts of pp. xxii–xxvi, 45–66 (McKay), 76–81 (McKay); No. 20, 1890, pp. lvi–lvii, 17–34 (Park); No 21, 1892, pp. 166–67.

Parl. Paper C.–4, 1894, pp. 10–12, 17–20, part of pp. 32–48 (bound in Mines Rep.); 2nd ed., 1897. Parl. Paper C.–6, 1894, p. 6 (bound in Mines Rep.).

Trans. N.Z. Inst., vol. 40, 1908, parts of pp. 72–79, 110–22 (A. M. Finlayson); vol. 41, 1909, part of pp. 64–84 (Finlayson).

Cotton, C. A.: "Block Mountains in New Zealand," *American Journal of Science*, vol. 44, Oct., 1917, pp. 249–93.

41. MANIOTOTO COUNTY.

The geology of Maniototo County is similar to that of Vincent County. On its north-eastern boundary Permo-Carboniferous rocks probably appear in the Hawkdun and Kakanui ranges. Old Mesozoic argillites and greywackes are believed to form much of the Kakanui Mountains. Tertiary strata are better developed than in Vincent County, and are known to include marine beds. The Maniototo Plain is a large intermontane depression which shows several long prolongations to the south: these are the Manuherikia Valley, Ida Valley, Upper Taieri Plain, and Strath Taieri, of which the two former are in Vincent County. Volcanic rocks of no very ancient age form a number of isolated masses, principally on the south-east side of the Maniototo Plain.

No limestone is known to exist in Maniototo County,* but a sample of marble from the county was obtained by Sir James Hector about 1882, and this not improbably came from the old Mesozoic or Permo-Carboniferous rocks of the Hawkdun or Kakanui mountains. The Tertiary strata, both fresh-water and marine, may be marly in places. Perhaps also Quaternary marl of the Lake Hayes type exists, as is perhaps indicated by analyses Nos. 2 and 3 below, though No. 3 represents a peculiar deposit containing much magnesium carbonate.

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* W. N. Blair (as previously cited, 1879, p. 99) states that "lime" exists in considerable quantity in the Maniototo Plains district. See also reference to limestone near Dansey's Pass (p. 257 of this bulletin).

	(1)	(2)
Carbonate of lime	95·94	30·90
Carbonate of magnesia	2·88	4·84
Alumina and iron oxides	0·16	4·34
Silica, or matter insoluble in acid	0·91	59·92
Water	0·11	..
	100·00	100·00

References.—(1) Marble from Maniototo, forwarded by Dr. Hector. Col. Mus. and Lab. 18th Ann. Rep., 1883, p. 44. Lab. No. 3387. It would be interesting to ascertain the exact source of this sample. Probably it was a specimen forwarded by post or otherwise to the Geological Survey.

(2) From "Central Otago," forwarded by G. M. Marshall. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 1162. Assigned to Maniototo as the most probable county.

	(3)
Silica	15·30
Iron oxide	2·73
Alumina	5·97
Lime*	23·12
Magnesia†	13·55
Alkalies	1·00
Carbonic anhydride	32·40
Water and organic matter	5·93
	100·00
*Equivalent to calcium carbonate (per cent.)	41·29
†Equivalent to magnesium carbonate (per cent.)	28·46

Reference.—(3) So-called clay from mining reserve, Hyde, forwarded by Mr. S. C. Hore, Naseby, per Geological Survey, July, 1915. Lab. No. F 837.

Summary of Limestone Resources and of Means of Transport.

On the strength of the evidence stated above, Maniototo County cannot be said to have any limestone resources, but some exploration seems advisable. It must apparently obtain its lime from Milburn, in Bruce County; but if the branch railway reaching Dunback from Palmerston South were extended to Ranfurly, limestone could readily be obtained from Dunback or even from the Oamaru district. The Otago Central Railway-line traverses the Maniototo Plain, and therefore gives access to most of the settled portions of the county. Roads are fairly numerous, though on the whole not very good.

Literature.

The following publications contain most of the principal references to the geology of Maniototo County. The Vincent County list may be consulted also.

Hutton, F. W.: "Geology of Otago," 1875.

Rep. of Geol. Explor., No. 16, 1884, parts of pp. xxii–xxvi, 44–45, 45–66, 91–95; No. 21, 1892, pp. 24, 158.

Parl. Paper C.-4, 1894, pp. 20–30, part of pp. 32–48 (bound in Mines Rep.).

Trans. N.Z. Inst., vol. 40, 1908, part of pp. 72–79 (Finlayson); vol. 41, 1909, part of pp. 64–84.

Cotton, C. A., 1917, as cited under Vincent County.

42. WAIHEMO COUNTY.

The geology of Waihemo County is decidedly varied. Schists of Palæozoic age occupy considerable areas. Old Mesozoic or possibly even in part Permo-Carboniferous (Maitai) rocks occur in the Kakanui Range and its continuation the Horse Range. The latter range also contains Cretaceous rocks, which are well displayed near Shag Point. Tertiary strata occur in patches on the tableland west of Dunback, and occupy a considerable portion of the Shag Valley, where they are mainly of marine origin. There are many isolated hills and masses of volcanic rock Late Tertiary in age.

The best-known limestone deposit in Waihemo County is the old Mesozoic (possibly Late Palæozoic) limestone on the north side of the Shag Valley near Dunback. It has been quarried and burnt for lime during many years.* According to McKay's map of 1887 a small patch occurs north of east from where Dunback now is; this probably is that now being worked for lime. A much larger area begins less than a mile to the westward, and extends north-west on the south-west slope of the Horse Range for nearly four miles. The average width of the belt as shown by McKay is well over half a mile, which seems unlikely to be correct. Cox's map of 1883 is decidedly different from McKay's. It shows a large area of limestone beginning not quite four miles from the coast and extending as a wide belt north-west for nearly four miles, beyond which are numerous scattered patches and minor belts of limestone for another three miles to the north-west. The Cretaceous rocks near Shag Point and elsewhere contain many calcareous concretions, mostly of spherical shape, and of all sizes up to many feet in diameter. These have previously been referred to as "Moeraki boulders" (see Waitaki County). Very commonly they are enveloped by cone-in-cone limestone.

A calcareous sandstone or sandy limestone† covers a considerable area in the eastern part of Waihemo County between the Shag and Pleasant rivers. It is partly concealed by volcanic rocks of younger age. The same rock covers a small area on the north bank of the Shag River about a mile from its mouth. McKay writes, "The limestones or calcareous sandstones of Puketapu are well exposed along the north bank of the Shag River, and form a flat tableland or terrace over the area indicated on the map" (1887 report, p. 20). Possibly similar but purer limestone occurs near Waihemo (see analyses Nos. 2 to 4 below).

The available analyses of Waihemo County limestones, with the exception of some made in 1865, are tabulated below:—

	(1)	(2)	(3)	(4)	(5)
Water	..	1·0	1·4	1·1	..
Carbonate of lime ..	73·64	87·0	88·0	96·0	58·01
Carbonate of magnesia ..	..	1·2	1·0	0·5	..
Oxides of iron (free) ..	..	0·6	0·8	0·6	..
Clay and other silicates ..	..	3·0	3·0	0·3	..
Sand (fine quartz-sand) ..	..	6·2	5·8	1·5	..
	..	99·0	100·0	100·0	..
Specific gravity.. ..	..	1·60	1·58	1·58	..

References.—(1) From Shag Valley, collected by Mr. Alex. McKay. Col. Mus. and Lab. 21st Ann. Rep., 1886, p. 37. Lab. No. 4266. On p. 60 the locality of this sample is given as Horse Range.

(2) to (4) So-called arenaceous limestones from Waihemo, forwarded by A. D. Bell, "Official Record N.Z. and South Seas Exhibition, held at Dunedin 1890–91" (Wellington, 1891), pp. 368, 369, 370, 371. Analyst, J. G. Black. Analyst's Nos. 9, 14, 14A. The general description given and the low specific gravity indicate a Tertiary age.

(5) From Palmerston South, forwarded by Department of Agriculture. Col. Lab. 30th Ann. Rep., 1897, p. 10. Lab. No. 6980.

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* In his "Geology of Otago," 1875, Hutton mentions that the Blue Mountain limestone was even then being burnt for lime.

† This rock is of Middle Tertiary (Oamaruian) age.

In 8th Ann. Rep. Dept. Agric., Chemical Division, 1900, p. 4, B. C. Aston gives the analysis of a sample of impure limestone forwarded by Mr. John Hodson, Shag Point. This was evidently a concretion, for it was supposed to be a coprolite. The analysis shows : Silica and matter insoluble in acid, 37·4 ; alumina and iron oxides, 6·7 ; lime, 26·8 ; magnesia, 1·8 ; carbonic anhydride, 22·9 ; phosphoric anhydride, 0·8 ; organic matter and water, 3·1 ; alkalies and loss, 0·5 : total, 100·0 This analysis has also been quoted under Waitaki County.

Hector and Skey, in their report of 1866, to which reference was made under Waitaki County, give analyses of a blue subcrystalline limestone from the Kakanui Range with 90·99 per cent. of calcium carbonate (see pp. 393–94, 448), and of a calcareous freestone from Waihemo with 61·60 per cent. of calcium carbonate (pp. 400, 451). (For further particulars see appendix to this chapter.)

W. N. Blair, in his publication of 1879 previously cited under Waitaki County, states (pp. 44–46) that hard bluish-grey and soft yellowish-white freestones occur in the Upper Waihemo Valley, chiefly in what is known as the Green Valley, about twenty miles from Palmerston South.

On page 60 of the 21st Ann. Rep. Col. Mus. and Lab., 1886, limestone and cone-in-cone limestone from Palmerston, collected by Mr. McKay, are listed as Nos. 4273 and 4274. The latter sample is stated on page 37 to have come from Amuri Bluff, and the full analysis has therefore been quoted under Kaikoura County. The probability is that the sample came from the Shag Point district. It contained 66·36 per cent. of carbonate of lime. Again, on page 60 of the report just mentioned, Nos. 4286 and 4287 are described as " stone for lime " and " chalk," Goodwood. These samples are most likely represented by analyses Nos. 4286/*a* and 4286/*b* on page 37, there ascribed to Kakanui. The carbonate-of-lime percentages given are 27·11 and 64·10. (See also Waitaki County.)

In March, 1919, one of the writers (P. G. Morgan) made a brief visit to the Milburn Lime and Cement Company's quarries and lime-works at Blue Mountain, on the east side of Inch Valley Creek, two or three miles north of Dunback. Limestone is being obtained from two quarries, one of which, situated a short distance from the works up Inch Valley Creek, has its floor about 390 ft. above sea-level, while the other, or main quarry, is worked from a level of about 530 ft. (barometric heights). The main-quarry face shows at least 150 ft. of excellent limestone, interbedded with several small bands and lenses of argillite (a slaty-looking rock). Argillite also underlies and overlies the limestone as a whole. It is locally called " schist," possibly because, owing to the presence of minute scales of mica, it is slightly schistose ; and this, unfortunately, has led to an erroneous impression that the limestone is interbedded with the true schists of Central Otago, whereas it belongs to a different and younger series. The limestone dips to the eastward, apparently not very steeply, but Mr. Robert McIntosh, the manager, states that at the south end of the quarry the dip is 1 in 1, or 45°. It is a hard bluish stone, said to contain a few small fossils, probably gasteropods. The maximum thickness of the limestone probably exceeds 300 ft.

Both ground limestone (so-called " carbonate ") and quicklime are produced at the works. The reducing portion of the plant consists essentially of a rock-breaker and an Allis-Chalmers No. 2 pulverizer, with a rated capacity of 45 tons per eight hours. The beaters supplied with the pulverizer were of manganese steel, and lasted twelve months : those now in use are of New Zealand make, and have a life of only six weeks. The reduction plant is driven by a 65-horse-power suction-gas engine, which is barely powerful enough for the work it has to do.

The lime-making plant consists of two ordinary pot kilns and a large gas-fired kiln. There is also a disused gas-fired kiln, which was not altogether a success in operation. The pot kilns are worked continuously, with Shag Point coal as the fuel. Limestone is charged in somewhat large lumps, with a maximum diameter of 6 in. or 7 in. The gas-fired kiln in use is of a German type. It is charged from the top with stone of the same size as that supplied to the pot kilns. At its base are several grates, under each of which is a space partly filled with water. The supply of air is regulated so that a large amount of combustible gas (mainly carbon monoxide, CO) is produced. This is burnt in the kiln some height above its bottom, the air-supply being regulated by dampers. The designers of the kiln are said to have recommended a temperature of 1,400° C., which is probably too high.* There is a tendency for the lime to clinker, and this fact indicates that a somewhat lower temperature than that in use, whatever it may be, is advisable. The temperature at the top of the kiln is tolerably high, and therefore the height (at present 52 ft.) could probably be increased with advantage. The original lining of the kiln consisted of imported firebrick, but a first-class firebrick made in Invercargill is now used for repairs and renewals. The lime-works are connected by a short railway-line with Inch Valley Railway-station.

The geology of Blue Mountain and the neighbouring district presents some peculiar features, which are well worthy of careful study. To what extent the limestone is lenticular, and to what extent the exposures are affected by powerful faults, cannot at present be stated.

Summary of Limestone Resources and of Means of Transport.

Waihemo County probably possesses considerable limestone resources. The ancient limestone of the Horse Range is sufficiently good for calcination. The Tertiary limestone varies in quality, and probably most of it is fit only for pulverization and local use. The Cretaceous rocks contain more or less impure calcareous concretions and calcareous claystones, but are not hopeful as a source of lime. More exploration and sampling by qualified persons are badly needed. It will be observed that in no case is the exact locality known of any of the samples of which analyses are quoted.

The eastern part of Waihemo County is traversed by the Dunedin–Christchurch Railway, and a branch line extends from Palmerston to Dunback. The Allandale Coal-mine is connected with the main railway-line by a short branch. The Otago Central Railway runs close to the western border of the county for ten miles or more. If the hilly nature of the county is taken into account it may be considered as moderately well roaded. There are one or two landing-places on the coast-line, but no true harbour.

Literature.

The chief publications having reference to the geology of Waihemo County are—

Rep. of Geol. Explor., No. 7, 1872, pp. 148–53 (von Haast); No. 8, 1877, part of pp. 19–26 (von Haast); No. 15, 1883, pp. xvi, 55–57 (Cox); No. 16, 1884, parts of pp. xxii–xxv, 45–66 (McKay); No. 17, 1886, pp. 182–84 (Hector); No. 18, 1887, pp. xv–xxviii, xxxi–xxxii, 1–23 (McKay); No. 21, 1892, pp. liii, 24–25, 45–50 (McKay).

Parl. Paper C.–4, 1894, part of pp. 30–48 (bound in Mines Rep.). 2nd ed., 1897.

Trans. N.Z. Inst., vol. 40, 1908, parts of pp. 110–22 (Finlayson); vol. 41, 1909, parts of pp. 64–84 (Finlayson).

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* Limestone may be calcined at 1,040° C. and less. Ordinary kiln temperatures are from 1,100° C. to 1,150° C. Orton and Peppel mention a semi-gas-fired kiln in which a temperature of 1,100° C. to 1,300° C. is maintained in the hottest part of the kiln. See "The Limestone Resources and the Lime Industry in Ohio," Bull. No. 4, Geol. Surv. of Ohio, 1906, p. 284.

43. Waikouaiti County.

In the west Waikouaiti County is largely composed of mica- and quartz-schist. In the eastern part marine Tertiary strata are well developed, and Late Tertiary volcanic rocks of basic types are very prominent, especially in the south-east, near Port Chalmers. The sandy limestone mentioned as occurring in the eastern part of Waihemo County extends southward in Waikouaiti County towards Waikouaiti North Head. From the descriptions given and from such outcrops as may be seen close to the railway-line it appears to be too impure to be of much value, but no doubt could be locally used as a soil-dressing in the pulverized state. The strata at Waikouaiti North Head (locally known as Cornish Mount or Mount Cronin) have been described by Park (1904), who states that the lowest bed is a foraminiferal blue clay, overlain by sandstone with calcareous layers. Puketeraki Peninsula seems to be composed of a similar sandstone. Near Seacliff calcareous sandstone is well developed, and along the shore-line forms cliffs over 200 ft. high, but nowhere passes into limestone. West of Blueskin Harbour (inner part) a belt of similar rock begins, and, according to Marshall's map of 1906, continues without interruption for many miles to the south-westward. At the head of the Waitati Stream it passes into Taieri County. According to Marshall two very small patches of calcareous sandstone [arenaceous limestone] occur at Dowling Bay and at Blanket Bay, on the western side of Otago Harbour (1906, p. 389). The Oyster Point calcareous sandstone or freestone mentioned by Hector and Skey in 1866 (pp. 399, 451) is probably in the latter locality.

No analyses of limestone or calcareous rock from Waikouaiti County have been found in the modern literature consulted, unless the two analyses of stone from Goodwood, mentioned under Waihemo County, refer to a locality or localities in Waikouaiti County, but quite a number appear in the publications cited below. Hector and Skey, in their report of 1866, give analyses of calcareous sandstones from Hawksbury and Pleasant River (p. 449), and of calcareous freestones from Pleasant River, Cornish Mount (Waikouaiti), and Hawksbury (pp. 399, 400, 401, 451). These analyses, together with that of the Oyster Point rock, are as follow:—

	(1)	(2)
True sand	25·0	29·5
Insoluble clay	17·9	Nil
Soluble clay	3·6	1·2
Oxide of iron	0·8	0·8
Carbonates of lime and magnesia	51·7	64·1
Alkaline chlorides	Traces	Nil
Hygroscopic water and water of constitution	1·9	Nil
	100·9	95·6
Specific gravity (calculated from weight of 1 cubic foot)	1·500	1·355

References.—(1) Calcareous sandstone, Hawksbury (? Puketeraki). Hector and Skey, as previously cited, p. 449. Analyst's No. 10.

(2) Calcareous sandstone, Pleasant River. Hector and Skey, p. 449. Analyst's No. 13.

	(3)	(4)	(5)	(6)
Insoluble matter	30·01	29·53	31·40	42·94
Soluble silica	1·00	0·63	..	0·70
Alumina	3·00	0·60	2·83	2·94
Iron oxide	Trace	0·83		0·90
Carbonate of lime	64·60	63·08	65·77	50·05
Carbonate of magnesia	1·16	1·10	Trace	1·70
Water and loss	0·22	4·22	..	0·77
	99·99	99·99	100·00	100·00
Specific gravity	..	2·307	..	..

References.—(3) Calcareous freestone from Oyster Point, Upper Harbour (Otago) West, forwarded by Mr. Hugh Calder, Caversham. Hector and Skey, pp. 399, 451. Analyst's No. 13.

(4) Impure close-grained limestone from Pleasant River, six miles from Waikouaiti, forwarded by Mr. W. Mason. Hector and Skey, pp. 399–400, 451. Analyst's No. 14.

(5) Calcareous freestone, Cornish Mount, Waikouaiti, forwarded by Mr. J. Hepburn, per Waikouaiti District Committee. Hector and Skey, pp. 400, 451. Analyst's No. 15.

(6) Calcareous sandstone from Hawksbury. Hector and Skey, pp. 401, 451. Analyst's No. 19.

The above analyses are further mentioned in the appendix to this chapter.

W. N. Blair, in "The Building Materials of Otago," 1879, besides quoting Hector and Skey's analyses, gives a number of others made by P. S. Hay (afterwards Engineer-in-Chief, Public Works Department) under the direction of Dr. J. G. Black (see p. 100). The limestone at Dowling Bay, some miles north of Port Chalmers, is mentioned on pages 103, 110, 112, 113, 114, and 115. Blair says there are five or six seams or layers of limestone at Dowling Bay and on Otago Peninsula with an aggregate thickness of 70 ft. The analyses of Dowling Bay limestone quoted by him are as follow:—

	(1)	(2)	(3)	(4)
Carbonate of lime and lime	92·91	84·03	78·87	69·70
Carbonate of magnesia	1·96	0·33	0·80	1·50
Soluble silica	0·31	..	0·62	0·31
Insoluble silica	2·82	10·93	12·70	18·87
Soluble alumina	1·09	1·23	1·52	0·80
Insoluble alumina	1·41	2·76	4·05	3·74
Soluble oxide of iron	0·43	0·98	0·35	1·30
Insoluble oxide or sesquioxide of iron	0·34	1·00	0·70	0·69
Alkalies, water, &c.	1·27	1·26	0·39	2·09
	102·54	102·52	100·00	99·00
Silica in form of sand (per cent.)	..	..	3·80	7·60

References.—(1) Bluish-grey limestone, top seam. Table I, No. 18.

(2) Drab granular limestone, fifth seam from top. Table III, No. 14.

(3) Drab granular limestone, second seam. Table III, No. 18.

(4) Dark-fawn limestone, third seam. Table III, No. 19. Seam 20 ft. thick (p. 115).

Blair mentions that a sample from the fourth seam, 20 ft. thick, contained 28·13 per cent. of sand.

In February, 1919, Dowling Bay was visited by one of the writers (P. G. Morgan). He observed various outcrops of limestone on the inland side of the road skirting the shore-line of Otago Harbour. These had strikes varying from south-west (210°) to north of west (280°), and westerly and northerly dips varying from 25° to 60°. The thickest band of limestone seen was about 20 ft. The quality of the stone was quite as variable as the strike and dip. Mr. Carey, a very old settler in the district, was interviewed, and stated that he and two others many years ago quarried limestone at the outcrop on the Port Chalmers side of Dowling Bay, and burnt it in a kiln close by. The limestone was also quarried as a building-stone, and used in the construction of various buildings at Port Chalmers.

According to Blair (pp. 121–22) a soft marl occurs at Waikouaiti and at Greytown (= Allanton, Taieri County) which has the following composition:—

Clay	27·84
Iron [oxide]	11·24
Lime [carbonate]	24·78
Sand	35·16
	99·02

The locality from which the sample was obtained is not stated.

Summary of Limestone Resources and of Means of Transport.

Waikouaiti County has poor limestone resources, but exploration may bring useful deposits to light. It is conveniently situated for obtaining lime from the Dunback district, and also has railway communication with the Oamaru and Milburn districts. From Waikouaiti to Oamaru by rail is forty-six miles, and to Milburn sixty-four miles. The Dunedin–Christchurch Railway traverses the eastern part of the county, through which the Main North Road from Dunedin has also been made. The remainder of the county appears to be poorly roaded.

Waikouaiti County shares Otago Harbour with Peninsula County and the town of Dunedin. At Port Chalmers are deep water and good wharves. Waikouaiti Bay could easily be made into a good harbour, but the inner portions of Blueskin or Waitati Bay (including Purakanui Inlet, &c.), on account of their shallowness, give shelter to small vessels only.

Literature.

The chief publications relating to the geology of Waikouaiti County are—

Rep. of Geol. Explor., No. 18, 1887, part of pp. xv–xxxi, 1–23 (McKay); No. 21, 1892, pp. lxiv–lxvii, 50–54 (McKay), part of pp. 167–68.

Parl. Paper C.–4, 1894, part of pp. 30–48 (bound in Mines Rep.). 2nd ed., 1897.

Quart. Jour. Geol. Soc., vol. 62, 1906, part of pp. 381–424 (Marshall); vol. 70, 1914, pp. 382–408 (Marshall).

Rep. Aust. Assoc. Adv. Sci., vol. 3, 1891, part of pp. 127–50 (G. H. F. Ulrich).

Trans. N.Z. Inst., vol. 36, 1904, pp. 418–30 (Park); vol. 40, 1908, part of pp. 72–79, 110–22; vol. 41, part of pp. 64–84; vol. 50, 1918, pp. 196–97 (J. A. Thomson).

44. TAIERI COUNTY (INCLUDING THE CITY OF DUNEDIN).

The geology of Taieri County is similar to that of the adjoining Waikouaiti County. Palæozoic schists occupy a great part of the county. Near Green Island Borough and Saddle Hill, coal-bearing rocks, apparently of Late Cretaceous age, extend over an area of several square miles. These are succeeded without known unconformity of any importance by a series of sands, marly claystones, greensands, and calcareous sandstones, the uppermost beds of which are certainly of Tertiary age. Volcanic rocks of interesting types are well developed, especially in and near the city of Dunedin. Thick beds of glacial-like gravels seen near Henley have provoked much discussion. The Strath Taieri Plain, near Middlemarch, is an extension of the Maniototo Plain (see Maniototo County). The Taieri Plain, south-west of Dunedin, is in an analogous depression or basin, the alluvial surface of which is almost at sea-level; in fact, the tides enter the two lakes, Waipori and Waihola (correctly Waihora), near its southern end.

The belt of calcareous sandstone, mentioned under Waikouaiti County as beginning west of Blueskin or Waitati Harbour, continues south-westward and south through the headwaters of the Silverstream, Abbot's Creek, &c., to the Green Island district. It is broken by the lower valleys of Abbot's Creek and the Kaikorai Stream, but is seen again on the slopes of Saddle Hill, and is prominent on the ridge south of Green Island Borough and along the sea-coast east of Black Head. It is also seen at both ends of the Caversham Railway-tunnel (hence the name "Caversham stone") and in various parts of the upper Kaikorai Valley. The Caversham sandstone is most calcareous immediately south of Green Island Borough and on the coast near Black

Head. In the former locality it may merit the name of arenaceous limestone Hector and Skey in 1866 (p. 400) mention the "old lime-kiln quarry" in Kaikorai Valley, and hence it may be supposed that an attempt to calcine the calcareous rock of that locality was made some time prior to 1865.

At Whare Flat (Upper Silverstream) the Tertiary sandstones and limestones, according to Marshall (1906, p. 389), have a thickness of about 1,000 ft. How much of this is limestone is not stated.

At Burnside a highly calcareous marl below the horizon of the Caversham sandstone, discovered about 1903, has been quarried for cement-making purposes since 1905. This marl, which is said to contain from 15 to 50 per cent. of lime (*i.e.*, calcium carbonate) will be again mentioned in Chapter V (Part II).

Near Brighton, at a still lower horizon, is a patch of highly calcareous conglomerate, underlain by sands and shales containing coal. This contains numerous specimens of a Belemnite, and is therefore considered to be of Cretaceous age. About twenty-five years ago a lime-kiln was erected here, and some of the calcareous rock burnt, but its quality was so uneven and, on the whole, low-grade that the venture was soon abandoned.

In 1865 several samples of Caversham sandstone were shown as building-stones at the New Zealand Exhibition, and this led to analyses being made by W. Skey, who was then analyst to the Geological Survey of Otago. Two freestones (Nos. 17 and 21) from Kaikorai Valley contained 60·86 and 40·45 per cent. of calcium carbonate respectively (Hector and Skey, 1866, pp. 400, 401, 451). A freestone (No. 18) from Sibbald's Quarry, Caversham, contained 51·22 per cent. of calcium carbonate (Hector and Skey, pp. 400–1, 451). These three analyses with other particulars are again mentioned in the appendix to this chapter. A grey-coloured freestone or impure concretionary limestone (No. 11, p. 399) from the vicinity of Dunedin, exhibited by Hugh Calder, Caversham, had the following composition (p. 451): Carbonate of lime, 68·51; carbonate of magnesia, trace; soluble alumina, 1·79; soluble oxide of iron, 0·79; soluble silica, 0·72; insoluble matter, 27·65; water, &c., 0·54: total, 100·00. Specific gravity, 2·549.

Hector and Skey (p. 449) also give the following four analyses of "calcareous sandstones" from Kaikorai and Caversham:—

	(1)	(2)	(3)	(4)
True sand ..	21·0	28·0	27·6	24·4
Insoluble clay ..	25·9	1·0	None	17·6
Soluble clay ..	3·4	4·5	2·4	1·5
Carbonates of lime and magnesia ..	42·1	62·8	68·5	53·0
Oxide of iron ..	1·7	1·8	0·8	1·4
Alkaline chlorides ..	None	None	None	0·2
Constitutional and hygroscopic water ..	5·9	0·6	4·2	2·0
	100·0	98·7	103·5	100·1
Specific gravity (calculated from weight of 1 cub. ft.) ..	1·256	1·465	1·475	1·273

References.—(1) Buff-yellow calcareous sandstone from Kaikorai (*a*). No. 8 of table

(2) (3) Greyish-yellow calcareous sandstone from Kaikorai (*b*) and Kaikorai ? (*c*) respectively. Nos. 11 and 12 of table.

(4) Bluish-grey calcareous sandstone from Caversham. No. 9 of table.

Hector and Skey (p. 396) state that the above analyses (with others) have been taken from the reports of the Government survey of Otago, 1864, p. 125. (See also appendix to this chapter.)

No analyses of any rock approaching limestone are known to have been made on material from Taieri County since 1865. The following analysis represents the Burnside marl:—

Silica	35·3
Alumina	8·7
Iron oxide	2·6
Lime	17·9
Magnesia	1·0
Soda and potash	1·3
Carbonic anhydride	13·7
Water	16·7
Organic matter	2·8
	100·0

Reference.—Forwarded by Mr. E. R. Green, Inspector of Mines. Col. Lab. 37th Ann. Rep., 1904, p. 9. Lab. No. 9558. The composition of the burnt stone is also given. The water percentage—16·8—is too high to be representative of the main body of the marl.

W. N. Blair (as previously cited, 1879, pp. 121–22) mentions a soft calcareous and ferruginous marl found at Waikouaiti and Greytown (now Allanton). (See also Waikouaiti County.)

In 1917 Mr. H. S. Molineaux, of the Reefs, near Barewood, forwarded a sample of limestone to the Dominion Laboratory which contained 97 per cent. of $CaCO_3$. (Dom. Lab. 51st Ann. Rep., 1918, p. 19; Lab. No. H 544.) The locality, Barewood, assigned to this sample must be queried.

Summary of Limestone Resources and of Means of Transport.

Taieri County appears to have no limestone deposit of undoubted value. The so-called Caversham sandstone in places may be sufficiently calcareous to be worth pulverization, but in the absence of representative analyses this remains doubtful. The calcareous conglomerate at Brighton may possibly also be utilized after pulverization. The Burnside marl could no doubt be applied locally as a soil-dressing. It is fairly hard for a marl, and the analysis quoted is not likely to be representative so far as its water percentage is concerned. Milburn is the nearest locality to Taieri County where good lime can be made. From here by rail to the south border of Taieri County is less than ten miles, to Mosgiel is twenty-two miles, and to Middlemarch is sixty-two miles or a little less.

Thanks to its railways, Taieri County has good means of communication and transport. The Dunedin–Invercargill Railway traverses the county a few miles from the coast. At Wingatui the Otago Central line begins, and passes in a northerly direction through the county. A short branch line connects Outram with Mosgiel. Near Dunedin the roads are, as might be expected, fairly good, and the same statement applies to some of the more settled portions of the county. The inland districts, however, are on the whole rather poorly roaded. The county adjoins the important port of Dunedin, to which a channel navigable for fairly large vessels has been made by the expenditure of much money. The Taieri River can be entered by small vessels, and is navigable for a few miles above its mouth.

Literature.

A great deal of attention has been given to the volcanic rocks near Dunedin, and not all the literature can well be cited here. The following publications contain most of the more important references to the geology of Taieri County:—

Hutton, F. W.; "Geology of Otago," 1875.

Rep. of Geol. Explor., No. 7, 1872, pp. 170–72 (Hector); No. 8, 1877, pp. 59–60 (McKay); No. 10, 1877, pp. xvii–xix, 143–54 (R. B. Denniston); No. 13, pp. 153–55 (W. Rowe); No. 18, 1887, pp. xxix-xxxi; No. 21, 1892, pp. liii–lviii, lxvii, 43–45 (McKay), part of pp. 50–54 (McKay), 54–55 (McKay), 164–66.

Parl. Paper C.-4, 1894, part of pp. 32–48 and geological map at end (McKay).

Trans. N.Z. Inst., vol. 34, 1902, part of pp. 444–47; vol. 40, 1908, parts of pp. 72–79, 110–22; vol. 41, 1909, part of pp. 64–84, 111–26 (Cotton).

Quart Jour. Geol. Soc., vol. 62, 1906, part of pp. 381–424 (Marshall).

Aust. Ass. Adv. Sci., vol. 3, 1891, part of pp. 127–50 (G. H. F. Ulrich).

45. PENINSULA COUNTY.

With the exception of one or two patches of Tertiary marine strata and some superficial deposits, Peninsula County is wholly composed of volcanic rocks. Calcareous sandstone or arenaceous limestone outcrops at 500 ft. above sea-level near Sandymount schoolhouse, where it dips at 30° to the south-west (Marshall), and again to the north-east across Hooper's Inlet, where the dip is in the same direction but steeper. C. N. Boult states that sandstone forms cliffs along the south shore of Peninsula County (that is, near Sandymount—a fact apparently not observed by Marshall), and refers in his paper and map of 1906 to other outcrops in the neighbourhood of Harbour Cone. Hutton (1875, p. 48) states that a belt of Oamaru rocks appears between Boat Harbour and Macandrew Bay, "north of Harbour Cove" (? Cone). It consists of sandstone, yellow and brown limestone. The last-named rock contains 87 per cent. of carbonate of lime. It appears that at least one lime-kiln was in operation in Peninsula County prior to 1875 ("Official Handbook of New Zealand," 1875, p. 107), and in 1879 there were kilns in two localities, operated by Messrs. Macdonald and Robertson respectively (W. N. Blair, as cited below, p. 110). Robertson's kilns were at "Glenmore."

Hector and Skey (1866, pp. 394, 448, Nos. 18 and 19) give analyses of samples of compact dark and yellowish limestones from Portobello, one with 86·80 per cent. and the other with 81·10 per cent. of calcium carbonate. These were evidently from the locality mentioned by Hutton. The analyses are quoted in full in the appendix at the end of this chapter.

W. N. Blair has a good deal to say about the Otago Peninsula limestone. His remarks will be found on pages 31, 94–95, and 109–15 of "The Building Materials of Otago," 1879. The following analyses of Peninsula limestone quoted by him were made by P. S. Hay under the direction of Dr. J. G. Black (see p. 100):—

	(1)	(2)	(3)	(4)
Carbonate of lime and lime ..	86·05	82·03	77·97	69·46
Carbonate of magnesia ..	2·22	Trace	1·98	2·26
Soluble silica	0·20	0·36	0·22	0·16
Insoluble silica	7·00	9·10	10·51	18·69
Soluble alumina	0·90	2·30	1·61	2·10
Insoluble alumina	3·57	2·53	4·21	3·16
Soluble oxides of iron ..	0·97	2·80	1·53	2·34
Insoluble oxides of iron ..	0·55	0·55	0·85	0·95
Alkalies, water, &c.	1·46	0·33	1·12	0·97
	102·92	100·00	100·00	100·09
Silica in form of sand (per cent.)	3·17	2·67	3·60	7·03*

*Includes some clay.

References.—(1) Compact dark-fawn limestone. Table III, No. 13. Sample from second highest bed at Macdonald's quarries (p. 112).

(2) Compact fawn limestone. Table III, No. 15. Sample from same locality as No. 1.

(3) Fawn-coloured limestone. Table III, No. 17. Sample from top seam at Macdonald's.

(4) Dark-fawn limestone. Table III, No. 19. Sample from lowest seam at Macdonald's.

According to Blair a sombre-brown limestone exists in large quantity on the eastern side of Otago Peninsula, but in a position difficult of access (p. 31). Limestone occurs at Seal Point on the southern side of the peninsula, "is near the surface from the ridge south of Mr. Macdonald's kilns to the gully at Harbour Cone," and appears at the head of Hooper's Inlet.

In February, 1919, one of the writers (P. G. Morgan) inspected the limestone-quarry near Sandymount schoolhouse, now being worked by Mr. J. Riddell. The observations made were not altogether accordant with those of Marshall, summarized in a previous paragraph. The quarry is about 600 ft. above sea-level. The face, about 60 ft. high, consists of hard blue limestone with one prominent layer of sandy claystone. The strike is north-east to south-west (216°), and the dip over 20° to the north-west. The upper layers of limestone are arenaceous, and do not contain over 70 per cent. of calcium carbonate. The middle layers are said to have about 80 per cent. of calcium carbonate, and the lowest layer worked as much as 94 per cent. Limestone outcrops over some acres, and the quantity of stone in sight is considerable. *Pecten huttoni* (Park) and a ribbed *Pecten*, probably *P. hutchinsoni* Hutton, are tolerably abundant. Other fossils also occur. At the time of the visit mentioned above, the limestone, after being broken to a suitable size in a jaw-crusher, was being calcined in a kiln 25 ft. deep and 9 ft. in diameter. The maximum output of this kiln is 10 tons per day, but the average production is much less. Most of the lime produced is transported by motor-wagon to the Milburn Lime and Cement Company's works at Dunedin. The fine material produced by the rock-breaker is used in making asphalt for footpaths, &c. Mr. Riddell also has a pulverizing plant, which was idle at the time of Mr. Morgan's visit.

Summary of Limestone Resources and of Means of Transport.

The limestone resources of Peninsula County are not great. It is close to the Dunedin railways, and has excellent sea communications by virtue of its position. It is well roaded, the volcanic rocks of the county supplying an abundance of road-making material.

Literature.

The chief references to the geology of Peninsula County are—

Hutton, F. W., and Ulrich, G. H. F.: "Geology of Otago," 1875, pp. 48, 56, 165–68, &c.

Rep. of Geol. Explor., No. 20, 1890, pp. 34–36; No. 21, 1892, p. 160.

Trans. N.Z. Inst., vol. 38, 1906, pp. 425–26 (C. N. Boult).

Marshall and Ulrich, as quoted under Taieri County.

46. FIORD COUNTY.

The most ancient rocks of Fiord County are supposed to be gneisses and schists of various types. These rocks cover large areas. Granite is abundant, and ultra-basic igneous rocks are probably present. In the south-west argillites and greywackes of Ordovician age are known to exist, and here also small patches of Tertiary sedimentary rocks make their appearance. In several places the gneisses and schists contain bands of marble, the origin and age of which are difficult to ascertain. The possible passage of ultra-basic rocks into magnesite or other carbonate at Milford Sound has already been mentioned in discussing Lake County, but so far no evidence suggesting a similar origin for the Caswell Sound and other marbles of Fiord County has been advanced.

According to McKay a band of grey or bluish marble 200 ft. thick, dipping to the south of east, is exposed on the north side of Caswell Sound. It forms a ridge on the eastern side of a little bay, and can be traced for some distance to the northward. At many places the marble contains scales of mica and graphite, as well as nests of iron-pyrites, the latter a very objectionable constituent in building or ornamental stone. On the south side of Caswell Sound there is a band of white marble 45 ft. to 50 ft. thick, which dips at 45° to the south-west. This appears to live for some distance southward. In November, 1881, when visited by McKay, it was being quarried in the hope that it might be profitably sold as a statuary or monumental stone, but apparently large flawless blocks could not be obtained, and the enterprise failed. Other particulars will be found in McKay's report.

In 1863 Hector observed pieces of marble in morainic débris at the head of a small cove off Crooked Arm. On the south side of Dusky Sound, between Fanning's Cove (probably Fanny Bay of the maps) and the upper end of Cooper's Island, a layer of crystalline limestone or marble about 40 ft. thick, enclosed in gneiss or schist, was worked without success many years ago. The marble consists of alternating bands of blue and white colour. According to Park, who visited the locality in January, 1888, the rock appears free from joints and flaws, and is in an accessible position close to deep sheltered water. First-class lime could be made from it. During his visit of 1863 Hector observed veins of calcite in the granite of Passage Island, Chalky Inlet (p. 486 of report cited below). According to Hutton ("Geology of Otago," 1875, p. 77) cipollino, a variety of marble, occurs at Thompson's Sound.

Little or nothing is known about the calcareous contents of the Tertiary rocks near Chalky and Preservation inlets. The white rocks of Chalky Island are described by Hector as soft sandy strata, and by Hutton (1875, p. 50) as grits and chalk-marl. From McKay's account it may be gathered that impure chalky limestone, marly shale, &c., occurs at Gates's, a small harbour between the Coal Burn and Wilson River, and at the Green Islets, farther to the east. (1896 report, pp. 38–39.)

Summary of Limestone Resources and of Means of Transport.

The ancient marbles of Caswell, Dusky, and perhaps other sounds and inland localities appear to form the chief limestone resource of Fiord County. The county is at present almost uninhabited, and is uninviting from an agricultural point of view, but it contains immense reserves of water-power, and its marbles may yet be found of value for the manufacture of carbide of lime or of calcium nitrate or other fertilizer.

The county has no roads and very few tracks. The fiords indenting the sea-coast therefore form the principal means of communication. Lakes Te Anau and Manapouri are partly in the county, and afford a certain amount of access from the east.

Literature.

Among the publications dealing with the geology of Fiord County are—

Hector, J.: "Report of a Geological Expedition to the West Coast of Otago." *Otago Provincial Gazette*, Nov. 5, 1863, pp. 435–78 (see especially pp. 449–60)

Rep. of Geol. Explor., No. 9, 1877, pp. 30–31; No. 11, 1878, pp. 10–13; No. 13, 1881, pp. 150–53, 159–66; No. 14, 1882, pp. 115–18 (McKay); No. 19, 1888, pp. xxxviii, 9–15 (Park); No. 21, 1892, p. 152.

Parl. Paper C.–11, 1896, pp. 31–47 (McKay). Bound in Mines Rep.

Trans. N.Z. Inst., vol. 39, 1907, part of pp. 496–503 (Marshall); vol. 42, 1910, part of pp. 255–67 (Speight).

47. WALLACE COUNTY.

Wallace is a large county with diversified topography. Part reaches to the west coast of Otago north of Fiord County, and, together with a narrow strip south of Lake Te Anau, consists of the same types of rock. East of this is a great fault, and the character of the country completely changes. Large areas of almost flat land surround short isolated or almost isolated mountain-ranges and hills of moderate height. The rocks present are argillites and greywackes, largely of Mesozoic age, but partly older, with minor masses of igneous rocks and a widespread series of Tertiary conglomerates, sandstones, shales, limestones, claystones, &c., with thick seams of brown coal towards the base. Tertiary volcanic rocks are also present. Alluvial deposits of greater or less thickness cover the flat country, which is now fairly well settled throughout.

Limestone of Tertiary age is fairly well developed in Wallace County. It outcrops near the mouths of the Waiau and Jacobs rivers at and below sea-level (Hutton, 1872, p. 110). An extensive area of limestone forms a more or less continuous strip west of Fairfax and Otautau. Limestone seems to continue round the northern end of the Longwood Range, and is seen on both sides of the Waiau River at Clifden. In this district are some well-known caves, which were visited by Hector as far back as 1863. Tertiary rocks extend down the valley of the Waiau River, and are seen near its mouth, as mentioned above. They cover most of the Lillburn watershed, and appear on the west side of Te Waewae Bay, where there is a considerable thickness of calcareous sandstone and possibly some impure limestone. No particulars of limestone in the Lake Manapouri and Lake Te Anau districts are obtainable.

Small outliers of limestone are found in the valleys of the Moonlight (Taringatura) Range, one forming Castle Rock* seven miles north-west of Dipton, and another a small hill north-east of Castle Rock (Hutton, 1872, p. 109). The dip at the latter locality is to the north-north-west (Hutton). Mr. M. Ongley reports that at Castle Rock limestone, mostly of good quality, forms the central part of a structural basin. The dips are inwards from all points, and the deposit is broken by several small faults. A stream has eroded a deep channel through the stone, and formed cliffs more than 100 ft. high. Some of the stone has been quarried and sawn to provide samples of building-stone.

Hector, who gives the earliest and in several respects the most complete account of Wallace County limestones, lays some stress on their impure sandy nature; and the same thing is done by Farquharson,† who says that the limestone on the banks of the Waiau is "not pure, averaging usually between 60 and 70 per cent." of $CaCO_3$ ("CaO," as printed in original, is evidently an error). The limestone, as a matter of fact, varies greatly within short distances both laterally and horizontally, and general statements concerning its quality cannot well be made without further exploration. Fairly good limestone, however, is obtainable in the Waiau Valley, and some of the limestone near Fairfax and Otautau appears to be of first-class quality. The available analyses of Wallace County limestones are given in the following tables:—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Water	1·1	1·0	1·3	1·1	1·0	1·1	1·0	0·7	..
Carbonate of lime ..	89·0	87·0	86·0	74·0	95·0	91·0	74·5	81·0	92·20
Carbonate of magnesia	1·0	1·2	1·4	1·6	1·7	1·4	0·9	1·4	..
Oxide of iron (free) ..	0·1	1·1	1·0	2·4	1·4	1·6	2·1	1·5	2·20
Clay and other silicates	2·5	2·1	3·2	7·7	0·1	1·1	7·0	4·3	5·60
Sand (fine quartz-sand)	6·3	6·8	7·1	13·2	0·7	3·5	14·2	10·0	
	100·0	99·2	100·0	100·0	99·9	99·7	99·7	98·9	100·00
Specific gravity ..	1·89	1·47	1·47	1·90	1·46	1·46	1·90	1·99	..
Analyst's number ..	17	18	18A	20	21	21A	22	24	11

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* There is another Castle Rock three miles north of west from Lumsden.

† Trans. N.Z. Inst., vol. 43, 1911, p. 457.

References.—(1) From Fairfax, forwarded by R. Meek.

(2) (3) (5) (6) From Merrivale (ten miles from Otautau), forwarded by Ellis Bros.

(4) (7) (8) From Merrivale, forwarded by R. D. MacLachlan.

These eight samples were shown as building-stones at the New Zealand and South Seas Exhibition, Dunedin, 1890–91. (See Official Record, 1891, pp. 368, 370, 371.) Analyst, J. G. Black.

(9) From C. Basstian, Aparima. Hector and Skey, 1866, as previously cited, pp. 393, 448. (See also appendix to this chapter.)

Dominion Laboratory analyses are as follows :—

	(1)	(2)	(3)	(4)	(5)	(6)
Matter insoluble in acid..	5·69	11·37	11·80	4·87	5·80	32·80
Alumina and iron oxides	1·94	..	..	..	..	..
Calcium carbonate ..	91·56	81·63	80·60	90·30	92·34	56·12
Magnesium carbonate and undetermined ..	0·81	..	..	..	..	..
	100·00	..	..	..	..	..

References.—(1) From Fairfax, forwarded by G. E. Meek. Dom. Lab. 47th Ann. Rep., 1914, p. 22. Lab. No. D 1034. "A good agricultural limestone, suitable for burning." Quicklime in calcined stone, 86 per cent.

(2) From Section 30A, Waiau Survey District, obtained by Mr. A. W. Rodger for the Geological Survey (per Mr. M. Ongley). Lab. No. G 1326/6.

(3) From Section 30B, Waiau Survey District. Lab. No. G 1326/7. Obtained by Mr. A. W. Rodger for the Geological Survey.

(4) From Lambie's, Orawia, Waiau Valley. Lab. No. G 1326/8. Obtained by Mr. A. W. Rodger for the Geological Survey.

(5) From top of limestone hill west of road running past the Castle Rock, Taringatura Survey District. Lab. No. G 1326/1.

(6) Arenaceous band below No. 5. Lab. No. G 1326/9. Phosphoric anhydride, 0·13 per cent.

Samples (5) and (6) were collected by Mr. M. Ongley in 1916, and are average samples representing large bodies of stone.

Summary of Limestone Resources and of Means of Transport.

Wallace County has large limestone deposits, but the quality is variable, and much exploration and careful sampling are required in order to arrive at a just estimate of their value. Some of the limestone is fit for calcination; much is evidently better suited for pulverization. A few years ago Mr. A. W. Rodger used a small Devil disintegrator at Birchwood Station, and another machine of the same type is being or has been used near Clifden.

Means of communication in Wallace County are now very different from what they were at the time of Hector's visit in June, 1863. A railway runs from Invercargill to Tuatapere, on the Waiau River, and a branch extends from Thornbury to Nightcaps. The Invercargill–Kingston Railway is close to the county boundary for some distance north and south of Lumsden, from which place a short branch has been constructed to Mossburn. The county now has many roads, most of which are macadamized.

Wallace County has the small port of Riverton, and there are various landing-places on the coast-line. Lakes Manapouri and Te Anau give the north-west part of the county some facilities for inland navigation. Bligh and George sounds (fiords) enter the north-west corner of the county, but at present are of no value as means of communication.

Literature.

The chief references to the geology of Wallace County are—

Hector, 1863 (as cited under Fiord County), pp. 442–46.

Hutton, F. W.: "Geology of Otago," 1875, pp. 6, 7, 14, 27, 49–50, 57, 68, 72, 79, 106–9, 111, 146, 150, &c.

Rep. of Geol. Explor., No. 5, 1869, pp. iv–vi, viii–ix; No. 7, 1872, part of pp. 89–112 (Hutton); No. 11, 1878, pp. 110–18 (Cox); No. 13, 1881, pp. viii–ix; No. 21, 1892, pp. 23, 175; No. 22, 1894, pp. xxxix–xliii (Hector, on Orepuki oil-shale).

Parl. Paper C.–9, 1899, part of pp. 15–16 (McKay, on auriferous ironsands).

Trans. N.Z. Inst., vol. 18, 1886, pp. 402–4 (W. S. Hamilton); vol. 25, 1893, pp. 88–106 (A. Hamilton); vol. 26, 1894, pp. 226–29 (A. Hamilton); vol. 43, 1911, pp. 448–53 (R. A. Farquharson).

4th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–9, 1910, pp. 3–5; 11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.–2B, 1917, p. 9.

48. Southland County.

The extreme north-east of Southland County reaches into the mica-schist area of Central Otago. South-westward the schists appear to pass more or less gradually into argillites and greywackes which may be either Palæozoic or old Mesozoic in age. Trias-Jura rocks form the Hokonui Mountains, most of the country east of the Mataura River, and, possibly, part of the Bluff Peninsula. In the latter locality and also in the Hokonui Mountains are masses of igneous rock of considerable antiquity. Tertiary strata occur as fringes to the mountainous areas—for example, at Waikaia and Waikaka; on the north, south, and west sides of the Hokonui Mountains; and as isolated patches on the Waimea Plain and on the broad plain south of the Hokonuis. They contain all the limestone now to be described.

The Forest Hill Range, an isolated ridge east of Winton, consists largely of limestone, which forms the top of the range and appears to dip to the south-west. A sample of limestone from the Forest Hill Range or its vicinity was forwarded to the Geological Survey in 1916 (per Mr. M. Ongley) by Mr. T. J. Garvie, Mabel. This contained 93·87 per cent. of calcium carbonate and 2·47 per cent. of matter insoluble in acid. Lab. No. G 1326/5.

To the north of the Forest Hill Range, a quarter of a mile or less south-west of Brown's Railway-station (on the Winton–Hokonui line), somewhat rubbly fossiliferous brown limestone is being quarried by Wright, Stephenson, and Co. on the top of a low hill which rises about 100 ft. above the railway-line. The limestone face is 25 ft. or more in height, and in addition about 3 ft. of soil is being stripped off the top. The upper 20 ft. to 25 ft. of the limestone is of better quality than that underneath. From the quarry the broken rock is trammed a few chains to a crushing and grinding plant, which is comparatively new, and is said to be capable of pulverizing 100 tons per day (of eight hours ?). The stone first goes through a rock-breaker (jaw type), which reduces it to pass a 2 in. ring. It then gravitates to a pair of rolls (made by an Invercargill engineering firm), which reduce it to a small size. The discharge from the rolls is scraped forward by a mechanical device to an elevator, which discharges into an inclined revolving drying-cylinder, roughly 20 ft. long. The material discharged at the lower end of the cylinder is elevated to a shaking-screen. The oversize goes to a fine pulverizer of the beater type, whilst the fine product passes to a hopper, where it is joined by the material from the pulverizer. The pulverized limestone is sold to farmers for soil-dressing, and to freezing companies, who use it in the manufacture of artificial manures. In the beginning of 1917 the advertised price was 14s. per ton, but after May the price was to be raised to 15s. per ton. The plant is driven by steam. About twenty men are employed.

A quarter of a mile to the east, in another low hill, is a limestone-quarry formerly worked by Wright, Stephenson, and Co., but now abandoned.

A sample of limestone from the present quarry, taken by Mr. M. Ongley in 1916, contained 90·81 per cent. of calcium carbonate and 4·22 per cent. of matter insoluble in acid. Lab. No. G 1326/3.

Northward from Brown's, limestone outcrops more or less continuously in the low hills and ridges east of the railway to Kingston. About half a mile east of Limehills Railway-station the firm of J. G. Ward and Co. is quarrying limestone in a small detached hill. The limestone face is about 25 ft. high, and is overlain by 6 ft. of soil and subsoil. The limestone is calcined in three kilns with Nightcaps coal. The quality of the stone in this locality varies, and not all is fit for the kiln. A sample from the quarry, taken by Mr. M. Ongley in 1916, contained 92·34 per cent. of calcium carbonate and 3·60 per cent. of matter insoluble in acid. Lab. No. G 1326/2.

About three-quarters of a mile south-east of Lady Barkly Railway-station is a small hill of high-grade limestone, where the Lady Barkly Company has opened a quarry. The stone is trammed to the old sawmill near the station, and is there pulverized. A sample obtained by Mr. Ongley in 1916 contained 95·90 per cent. of calcium carbonate and 1·47 per cent. of matter insoluble in acid. Lab. No. G 1326/4.

A long patch of Tertiary rocks containing limestone forms a narrow strip on the south-west side of the Waimea Plains. This patch does not form hills, and cannot be distinguished in outline from the alluvial terraces of the plain (Hutton, 1872, p. 109). According to McKay's mapping of 1894 limestone covers an area three miles long, with a maximum width of over a mile, south-west of Waimea Railway-station. How far limestone is developed to the north-west and to the south-east is uncertain, but samples of limestone have been received by the Dominion Laboratory from Balfour, which is six miles to the north-west of Waimea, and from Croydon, which is sixteen miles to the south-east, and within a few miles of Gore. West of Waimea McKay saw a cliff of limestone 20 ft. high. He states that in the neighbourhood a bore passed through nearly 113 ft. of calcareous rock. It may be mentioned that this bore at a depth of 384 ft. 9 in. to 398 ft. 3 in. passed through 13 ft. 6 in. of pink crystalline limestone supposed by McKay to be of Permian age.

Hector and Skey in their report of 1866 give several analyses of Southland limestones, which are reproduced with other particulars in the appendix to this chapter. The more important details are given in the following table :—

Analyst's Number.	Locality.	Exhibitor.	Description.	Calcium Carbonate. Per Cent.
1	"Southland"	..	White, crystalline, homogeneous	98·80
2	Winton district (probably)	J. Hill	Bluish (or faint yellow), compact, crystalline	97·90
15	"Southland"	..	Grey, shelly	90·80

The following tables contain all the analyses of Southland limestones quoted in Dominion Laboratory reports or given by Aston in his list of 1915 :—

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Matter insoluble in acid, &c.	7·16	4·25	5·19	6·03	0·31	5·92	4·19	2·52	7·44	..
Alumina and iron oxides	1·70	2·31	2·94	2·76	0·22	0·24	4·35	1·37	2·25	..
Calcium carbonate ..	88·64	90·48	88·88	88·00	96·69	90·29	87·26	93·75	88·50	99·09
Magnesium carbonate ..	..	..	2·78	3·04	2·69	3·39	3·47	..	..	..
Water	..	..	0·21	0·17	0·09	0·16	0·73	..	..	..
	97·50	97·04	100·00	100·00	100·00	100·00	100·00	97·64	98·19	..
Quicklime (CaO) in calcined stone (per cent.)	84	88	84·0	82·5	96·2	86·4	82·7	..	..	98

	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Matter insoluble in acid ..	3·65	11·76	1·98	..	1·79	18·61	..	..	..
Alumina and iron oxides ..	..	4·02	0·51	..	Traces	Traces	..	..	..
Calcium carbonate ..	93·40	80·25	94·71	77·84	96·22	81·27	93·30	93·30	59·10
Magnesium carbonate ..	..	..	2·69	..	1·78	..	..	..	..
Water	..	..	0·11	..	0·21	..	..	..	..
	..	96·03	100·00	..	100·00	99·88	..	..	..
Quicklime (CaO) in calcined stone (per cent.) ..	90	72	93·2	..	95·2	..	..	..	..

References.—(1) (2) From Grove Bush, fifteen miles north-east of Invercargill. Aston, B. C., Jour. Agric., vol. 11, No. 4, Oct., 1915, p. 332. Analyst's numbers and date: G 206 and 207; 1906. (See also Dept. Agric. 14th Ann. Rep., 1906, p. 112, where fuller analyses are given.)

(3) to (6) From Hokonui (Forest Hill), forwarded by the Secretary, Department of Agriculture. Col. Lab. 31st Ann. Rep., 1898, p. 11. Lab. Nos. 7401/1–4. Nos. 7401/1, 2, 4, were rusty coherent limestones. The other sample was crystalline, and appeared to be only a part of a thin vein or band.

(7) Shelly limestone from Hedgehope, forwarded by Mr. John Gorman. Col. Lab. 33rd Ann. Rep., 1900, p. 11. Lab. No. 8551. (Ferric oxide, 3·92 per cent.; alumina, 0·43 per cent.)

(8) (9) Ground limestone sold in Southland, said to be from Forest Hill. Aston, B. C., as cited above. Analyst's numbers and date: G 366, 367; 1906.

(10) (11) (12) From Brown's. Same references as Nos. 1, 2, 8, and 9. Analyst's numbers and date: G 507, 508, 509; 1906.

(13) From The Dome, Southland, forwarded by Sir Julius Vogel (?). Col. Mus. and Lab. 20th Ann. Rep., 1886, p. 40. Lab. No. 3830/F.

(14) From Balfour, forwarded by R. A. Orr. Dom. Lab. 45th Ann. Rep., 1912, p. 20. Lab. No. B 1080. (Phosphoric anhydride, 0·22 per cent.)

(15) Chalk ascribed to vicinity of Bluff. Col. Mus. and Lab. 17th Ann. Rep., 1882, pp. 31–32. Lab. No. 3119. There is a suspicion that this sample came from Campbell Island.

(16) Disintegrated shells from Invercargill, forwarded by the Mayor. Col. Mus. and Lab. 26th Ann. Rep., 1892, pp. 28–29. Lab. No. 5786. (Organic matter, 0·12 per cent.)

(17) to (19) From "Invercargill," forwarded by the Commissioner of Crown Lands. Dom. Lab. 47th Ann. Rep., 1914, p. 21. Lab. Nos. D 597/1–3. (The first two each contained 0·05 per cent. of phosphoric anhydride, the third 1·39 per cent.)

A sample of limestone from Croydon, five miles north-west of Gore, forwarded to the Dominion Laboratory in 1915 by Mr. MacDonald, Reaby, Croydon, per the Hon. the Minister of Mines, had the following composition:—

Matter insoluble in hydrochloric acid	8·36
Soluble silica (SiO_2)	0·36
Alumina (Al_2O_3)	5·72
Ferric oxide (Fe_2O_3)	5·60
Lime (CaO)	43·48
Magnesia (MgO)	0·78
Carbonic anhydride (CO_2)	31·40
Moisture and organic matter	3·32
Alkalies and undetermined	0·98
	100·00
Calcium carbonate ($CaCO_3$) equivalent to lime (per cent.) ..	77·64
Calcium carbonate equivalent to carbonic anhydride (per cent) ..	71·36

Reference.—Dom. Lab. 49th Ann. Rep., 1916, p. 19. Lab. No. F 182. A fuller statement of the analysis than that contained in the laboratory report is given above.

According to the Handbook of N.Z. Mines, 1887, p. 28, marble occurs in the Nokomai district, "but no steps have been taken to test its quality or open out a quarry."

Summary of Limestone Resources, &c.

Southland County has large limestone deposits, conveniently situated with respect to the railways and the chief arable areas. In places the limestone is of variable quality. The beds are thin and well marked off from one another; and not only do they differ from one another, but as followed along the strike or dip the individual layers may change considerably within short distances. Some exploration and much careful sampling by experienced persons are necessary before the limestone deposits can be exactly appraised and a well-considered scheme for their intensive development set out. Southland and Wallace possess a very large area of arable land, practically all of which requires more or less heavy liming (W. D. Hunt, Jour. Agric., vol. 13, No. 2, Aug., 1916, pp. 87–96).

Means of Transport.

Southland possesses the good harbour of Bluff, together with several ports, such as Invercargill (New River estuary), Fortrose, and Waikawa, where small vessels may berth or find shelter. Thanks to its plains and wide valleys with easy grades, Southland has a better railway system than any other area of equal size in New Zealand. From Invercargill railways radiate east, north, west, and south. In all there are ten distinct railway-lines—namely, Invercargill–Tokanui, Invercargill–Gore–Dunedin, Edendale–Wyndham, Gore–Waikaka, Gore–Lumsden, Riversdale–Waikaia, Invercargill–Kingston, Winton–Hokonui, Invercargill–Riverton–Tuatapere, and Invercargill–Bluff. The county is almost correspondingly well roaded, so that facilities for the distribution of lime are unusually good.

Literature.

The chief references to the geology of Southland County are contained in the following publications:—

Hector, 1863 (as cited under "Fiord"), pp. 441–42.

Rep. of Geol. Explor., No. 5, 1869, pp. ii–iv; No. 7, 1872, greater part of pp. 89–112 (Hutton); No. 11, 1878, pp. vi–xii, 25–90 (Cox); No. 13, 1881, pp. xv–xvi, 39–48 (McKay); No. 18, 1887, pp. xlv, 120–21 (Park), 141–53 (Park); No. 19, 1888, pp. 72–74 (Park); No. 21, 1892, pp. lxviii, lxxi, 31–35 (McKay), 63–64 (McKay).

Parl. Paper C.–4, 1894, part of pp. 32–48 (bound in Mines Rep.).

Trans. N.Z. Inst., vol. 15, 1883, pp. 414–19 (W. S. Hamilton); vol. 19, 1887, pp. 452–55 (W. S. Hamilton); vol. 20, 1888, pp. 269–71 (Hutton); vol. 23, 1891, pp. 353–55 (Hutton); vol. 42, 1910, pp. 36–39 (J. A. Thomson); vol. 44, 1912, pp. 317–39 (L. J. Wild).

8th Ann. Rep. N.Z. Geol. Surv., part of Parl. Paper C.–2, 1914, pp. 147–54. 2nd ed., 1915.

Newell-Arber, E. A.: "The Earlier Mesozoic Floras of New Zealand." N.Z. Geol. Surv. Pal. Bull. No. 6, 1917. (See pp. 10, 12–17, &c.)

49. TUAPEKA COUNTY.

Tuapeka is an inland district, in which mica-schists and allied rocks of Palæozoic age are extensively developed. To the south-west and south these appear to pass more or less gradually into greywackes and argillites of Trias-Jura age. The other rocks of the county are Tertiary conglomerates, sandstones, shales, and lignite, together with Quaternary gravels and clays. The Tertiary conglomerate and the Quaternary gravels are auriferous, in places richly so. The first notable discovery of alluvial gold in Otago was made in 1861 at Gabriel's Gully, near Lawrence, by Gabriel Read. Edward Peters, a native of Bombay, had found gold in Tuapeka County as early as 1857, but did not announce his discovery.*

No limestone is known to be present in Tuapeka County. Any Tertiary limestone that may once have existed has long since been removed by denudation. Possibly ancient limestones may yet be discovered in the Blue Mountains, near Tapanui.

Means of Transport, &c.

Two railways enter Tuapeka County, the Milton–Lawrence–Beaumont line and the Waipahi–Tapanui–Edievale line. Owing to the hilly or mountainous nature of the county and the scarcity of good roadmaking material the roads are, on the whole, not very good. The Molyneux River is navigable for small steamers, but the rapid current prevents it from being used for transport purposes above Tuapeka Mouth.

Literature.

Part of Tuapeka County has been geologically surveyed in detail by Dr. P. Marshall, and the results of his work will be found in N.Z. Geol. Surv. Bull. No. 19, 1918, "The Geology of the Tuapeka District, Central Otago Division." The list of literature given in that bulletin on pages 8–10 covers practically all the publications relating to the geology of Tuapeka County.

50. BRUCE COUNTY.

The older rocks of Bruce County are similar to those of Tuapeka, but schists are not so prominent. Tertiary strata are much better developed, and contain valuable seams of brown coal; whilst near Milburn, four miles north of Milton, patches of usefully situated limestone are found. In the same locality deposits of rock phosphate, which will be described in Chapter V, have been worked since their discovery in 1902. The other rocks of Bruce County are basic volcanic rocks and the alluvial deposits of the Tokomairiro and other plains.

The Milburn limestone is shown by A. R. Andrew (1906) as outcropping north of Milburn on three sides of a basalt-flow that forms the upper part of trig. Q hill. It extends continuously under the basalt, but for practical purposes only the long U-shaped outcropping strip can be considered of much value. On the south-west side of the railway, on the lower slopes of Gorge Hill, are two patches of limestone, one of which is very small. The locality is mentioned in old geological reports under the name of "Waihola Gorge."

Andrew gives the following detailed section seen in the Milburn Lime and Cement Company's main quarry. The beds are mentioned in descending order, H being the youngest and A the oldest.

Band H: 30 ft. of siliceous limestone, with glauconite grains throughout.
Band G: 3 ft. of hard limestone, less siliceous than H.
Band F: 2 ft. of hard, tough, fairly siliceous limestone.
Band E: 6·5 ft. of tough limestone.
Band D: 3 ft. of very pure knubbly limestone.
Band C: 42 ft. of pure white limestone.
Band B: 35 ft. of limestone, pure above, but more and more glauconitic towards the base, where it merges into
Band A: Unknown thickness of glauconite sands.

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* From "Reports and Awards of the Jurors, N.Z. Exhibition, 1865," Dunedin, 1866, pp. 19 and 20, it appears that gold was first discovered in Otago in 1852. In the years 1856–58 the following persons (among others) reported or made discoveries of gold: Messrs. C. W. Ligar, J. T. Thomson, — Gillies, Alex, Garvie, and John Buchanan (later a member of the Geological Survey staff).

Each of these bands is described in detail by Andrew, who also gives analyses of bands H and C, quoted below, together with an analysis by the Dominion Laboratory (No. 1):—

	(1)	(2)	(3)
Matter insoluble in acid	10·10	5·50	2·21
Alumina and iron oxides	1·75	..	..
Lime (CaO)	48·36	..	54·12
Magnesia	0·50	..	..
Carbon dioxide (CO_2)	38·54	..	42·86
Phosphoric anhydride	..	0·15	0·018
Water	0·75	..	..
	100·00	..	99·208
Calcium carbonate, equivalent to lime (per cent.)	86·35	..	96·64

References. — (1) From Milburn, forwarded by the Chief Engineer of Roads (? Chief Engineer, Public Works Department). Col. Lab. 36th Ann. Rep., 1905, p. 9. Lab. No. 9402. The sample is described as a whitish limestone, dotted with a large number of greenish-black particles of chlorite. As was shown by Andrew, the greenish-black substance is glauconite.

(2) Andrew, A. R., Trans. N.Z. Inst., vol. 38, 1906, p. 454. Sample represents band H.

(3) Andrew, A. R., as cited above, p. 455. Sample represents band C.

The limestone being quarried at the Milburn Lime and Cement Company's quarry is arranged in comparatively thin laminæ from 1 in. to 5 in. thick. It is thus a flaggy stone. The laminæ are separated by narrow seams of sandy material, generally $\frac{1}{16}$ in. thick or less. Some of the parting layers are glauconitic, especially one about $\frac{1}{2}$ in. thick, near the middle of the face. The surfaces of the laminæ are not quite parallel, hence each lamina is visibly more or less lenticular. The dip is gentle, and on the average is to the south-east. Andrew states that the highest outcrop dips S. 42° E. at an angle of 8°. On the east side of the road the strata dip at 15° to 45° in a direction 10° south of east.

West of the Milburn quarry the limestone becomes more glauconitic, and may even approach calcareous greensand, but this condition does not hold everywhere.

The Milburn limestone has been quarried for lime-making purposes for over forty years (since some date prior to 1875). One of the earliest lime-burners was Mr. J. McDonald,* who for a few years was a member of the House of Representatives. At present the Milburn Lime and Cement Company is burning limestone in a number of pot and shaft kilns. It has built a plant consisting of rock-breaker, rolls, &c., for grinding limestone, and is also railing limestone to its cement-works in Dunedin, which have been established for considerably over thirty years. The quarry-faces vary from 45 ft. to over 100 ft. in height.

The Dominion Lime Company is quarrying limestone from a 50 ft. face westward of the Milburn Lime and Cement Company's ground. The amount of stone in sight is not large, but prospecting is expected to reveal further supplies under the clay overburden that obscures the outcrops in this locality. Most of the stone quarried is calcined in three pot kilns, two of which are constantly in operation. The company also has a grinding plant, which is worked intermittently.

A black limestone is said to occur in the Tokomairiro or Milton district, but the exact locality of the outcrop is unknown. (See Hutton, 1875, pp. 48, 113.)

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* The Mr. Macdonald mentioned on pp. 276 and 277 is probably the same gentleman.

W. N. Blair mentions the Milburn limestone under the name of "Waihola limestone" on pages 32–33, 102–3, and 106 of his "Building Materials of Otago," and gives the following analyses:—

	(1)	(2)	(3)
Carbonate of lime and lime	95·76	94·66	43·30
Carbonate of magnesia	Trace	Trace	Trace
Iron (oxide) and alumina	0·92	1·29	..
Insoluble sesquioxide of iron	..	..	2·40
Silica, &c.	3·32	4·05	27·60
Clay, partly insoluble	..	..	19·00
Alkalies, water, &c.	..	..	0·70
	100·00	100·00	93·00
Silica in form of sand (per cent.)	..	..	21·98

References.—(1) Soft, white, fossiliferous, granular limestone from east side of "Waihola Gorge." Table I, No. 13. See also pp. 102–3. Analysis by Dr. Hector.

(2) White compact hard limestone. Table I, No. 16. See also pp. 102–3. Analysis by Dr. Hector (?).

(3) Fine-grained grey soft limestone. Table II, No. 18. See also p. 106. Analysis made by P. S. Hay (under direction of J. G. Black).

Summary of Limestone Resources.

The only limestone known in Bruce County is that near Milburn. The deposits here are largely of high grade, and situated close to the railway and to important agricultural districts. Probably two-thirds of the limestone can be successfully calcined; the other third, if required, could be pulverized, and, as it is glauconitic, would furnish some potash and probably a little phosphate to the soils on which it might be used. A considerable amount of sampling is needed in order to ascertain the quality of the limestone throughout the area in which it is exposed.

Means of Transport.

Bruce County is traversed by the Dunedin–Invercargill Railway, from which a branch leaving the main line near Milton runs north-west to Beaumont via Lawrence. A short private line connects the Kaitangata Coal-mine with the main railway at Stirling. The Taratu and Lovell's Flat coal-mines also have private lines or tramways to their mines. The main roads of Bruce County are good, but those inland of the central depression traversed by the Dunedin–Invercargill Railway and in the coastal belt probably leave much to be desired. The mouths of the Taieri and Molyneux rivers can be entered by small vessels, and both streams are navigable so far as they impinge on the borders of the county.

Literature.

The chief references to the geology of Bruce County are—

Hutton, F. W., "Geology of Otago," 1875.

Rep. of Geol. Explor., No. 7, 1872, pp. 165–70; No. 10, 1877, pp. xix–xx, 140–42; No. 17, 1886, pp. x–xi, 1–5; No. 21, 1892, pp. lviii–lxiii, 148–49.

Parl. Paper C.-4, 1894, part of pp. 32–48 (bound in Mines Rep.).

Trans. N.Z. Inst., vol. 35, 1903, pp. 391–402 (Park); vol. 38, 1906, pp. 447–82 (A. R. Andrew). The Clarendon and Milburn phosphate deposits are described by Park and Andrew in the papers cited.

Macdonald, A. G.: "The Brown Coals of Otago." *Colliery Guardian*, vol. 104, 1912, Nov. 22, 29, Dec. 6, 13, pp. 1036–38, 1089–91, 1140–41, 1190.

11th Ann. Rep. N.Z. Geol. Surv., Parl. Paper C.-2B, 1917, p. 10.

N.Z. Geol. Surv. Bull. No. 19, 1918, as cited under Tuapeka County. This has reference to several localities in Bruce County.

51. Clutha County.

The principal rocks of Clutha County are conglomerates, greywackes, and argillites, which are largely of Trias-Jura age. It is possible that still older rocks are present, especially in the north of the county. Tertiary strata (sandstones, claystones, and lignite) are found in a few places, but are nowhere known to be more than slightly calcareous, except possibly in the Pomahaka district. Basic volcanic rocks and Pleistocene and Recent gravels, clays, &c., almost complete the list of rocks found in the county.

Means of Transport, &c.

Clutha County has no known limestone, and therefore must at present look to Milburn in Bruce County for its lime. Ultimately lime may also be obtainable from the Waimea Plain or elsewhere in Southland. From Milburn to Balclutha by rail is twenty-one miles, to Clinton forty-two miles, to Waipahi Junction fifty-two miles, to Owaka forty miles, and to Tahakopa (the present terminus of the Catlin's branch railway) sixty-four miles.

Besides being traversed by the Dunedin–Invercargill Railway, Clutha County has a branch line from Balclutha to Tahakopa, which will at some future time be continued to meet the Invercargill–Tokanui Railway. A branch also leaves the main line at Waipahi, and runs northward to Tapanui and Edievale, in Tuapeka County. Part of Clutha County is well roaded, but the roading-system, especially in the south of the county (owing to its hilly and bush-clad nature) is still incomplete. The county possesses the river ports of Port Molyneux and Catlin's River (Newhaven), and a coastline with various small indentations, some of which may be capable of sheltering small vessels.

Literature.

The chief references to the geology of Clutha County are—

"Geology of Otago," 1879.

Rep. of Geol. Explor., No. 8, 1877, pp. 60–73; No. 21, 1892, pp. 150–51.

Trans. N.Z. Inst., vol. 36, 1904, pp. 378–86 (Park), 477–79 (Speight).

Newell-Arber, E. A.: "The Earlier Mesozoic Floras of New Zealand." N.Z. Geol. Surv. Pal. Bull. No. 6, 1917, pp. 10–11, &c.

52. Stewart Island County.

The southern part of Stewart Island appears to be formed mainly of ancient granitic and, to a much less extent, schistose rocks, whilst the northern part consists largely of greywackes, argillites, and allied rocks (in places schistose), generally supposed to be of Palæozoic age. Hector states that "marble of good quality is also said to occur in massive bodies on the west coast." According to McKay the locality is opposite Rugged Island, and a small sample of the marble seen by him was saccharine, fine-grained, white, and free from stains (1890, p. 80).

Means of Communication, &c.

Stewart Island has hardly any roads and few tracks. On its east coast are Paterson Inlet and Port Pegasus, both good harbours. There are various other inlets on the east coast, but the west coast seems to be without any good harbours, though in places shelter for vessels may be obtainable. As yet little or no agriculture is practised, the principal industries being fishing and the milling of timber.

Literature.

The principal references to the geology of Stewart Island are—

Hector, J., 1863 (report cited under Fiord County), pp. 447–48.

Trans. N.Z. Inst., vol. 2, 1870, pp. 183–86 (Hector).

Hutton, F. W.: "Geology of Otago," 1875, pp. 12, 18, 34, 37, 113, 114, 118, 119, 150–51.

Rep. of Geol. Explor., No. 20, 1890, pp. liv–lv, 74–85.

53. Chatham Islands County and Outlying Islands.

CHATHAM ISLANDS.

According to von Haast (1869) some beds of limestone fringe the south-western shores of Te Whanga Lagoon, Chatham Island, east and north-east of Waitangi. The limestone, he states, is white, crystalline, and somewhat vesicular.

On the western side of Pitt Island are calcareous fossiliferous tuffs, which pass into tufaceous whitish limestone containing numerous Tertiary fossils. Beds of very fine semi-crystalline limestone overlie the tufaceous limestone. In part the Tertiary limestone, according to Hector (1870), is a true lithographic stone. This statement presumably refers to the very fine (-grained) limestone mentioned by von Haast. In 1868 Mr. H. D. Traill collected specimens of chalky rock at Chatham Islands. Somewhat later Mr. S. Percy Smith collected, among many other specimens, one of limestone highly charged with salt, and another of magnesite (Col. Mus. and Lab. 4th Ann. Rep., 1869, p. 12).

The following analyses of limestone from Chatham Islands were made by A. A. Bickerton in 1917. The samples were collected by Mr. C. S. Barker. Nos. 2 and 3, especially the latter, are decidedly phosphatic.

	(1) Per Cent.	(2) Per Cent.	(3) Per Cent.
Calcium oxide	49·39	50·51	47·01
Equal to carbonate	88·20	90·20	84·00
Phosphoric anhydride	0·26	0·77	3·33
Equal to tricalcic phosphate	0·56	1·68	7·26

Literature.

The geological literature relating to the Chatham Islands is scanty. The following references occur in the Trans. N.Z. Inst.: Vol. 1, 2nd ed., 1875, pp. 119–27 (H. H. Travers), 127–29 (von Haast); vol. 2, 1870, p. 183 (Hector); vol. 4, 1872, pp. 63–66 (W. T. L. Travers—mainly biological).

CAMPBELL ISLAND.

Marshall states (1909, p. 686) that somewhat lamellar limestone reaching 500 ft. in thickness outcrops round the shores of North-west Bay. Limestone is also seen at Tucker and Venus coves (west end of Perseverance Harbour), and in a bay at the south-west corner of the island. It rests on shale, and is overlain, apparently unconformably, by volcanic tuff. In places the limestone is argillaceous, but the upper layers are "almost pure oceanic limestone, without a trace of detrital matter." It appears perfectly homogeneous to the eye, but "in section a few grains of glauconite are occasionally seen; except for these the whole rock consists of extremely fine calcareous matter, in which tests of Foraminifera can be seen." On the western side of North-west Bay the limestone has been changed to a fine-grained marble. It dips at various angles and in various directions, and is traversed in all directions by intrusions of igneous rock, which on the cliffs of North-west Bay form a perfect network

Marshall thinks that the limestone is probably of Miocene age. Hector, judging from the occurrence of chalk, flints, and fossil wood, places it in the Upper Cretaceous (1896, p. 737). The earlier view is supported by the probable occurrence of *Conchothyra parasitica*, as recorded by Marshall (1909, p. 700).

The following analysis represents a sample of "finely comminuted chalk forwarded as a clay from Tucker Cove, Perseverance Harbour," to the Colonial Laboratory in 1885 or 1886. The material was dried at 212° F., and hence moisture is nil.

Carbonate of lime with a little magnesia	96·1
Iron oxide	0·6
Alumina	1·1
Silica (? matter insoluble in acid)	2·2
	100·0

Reference.—Forwarded by Mr. T. B. Gray. Col. Mus. and Lab. 21st Ann. Rep., 1886, p. 36. Lab. No. 4121.

On a former page, under Southland County, an analysis of chalk ascribed to the vicinity of Bluff was quoted. It seems quite probable that this sample also came from Campbell Island. (See Col. Mus. and Lab. 17th Ann. Rep., 1882, pp. 31–32.)

Aston (1909, pp. 766–67) gives the following analyses of limestone and chalk from Campbell Island:—

	K 2662	K 2649	K 2711	Analysis by G. T. Prior.
Water	2·51	1·95	3·80	1·44
Silica (SiO_2)	19·30	1·91	64·06	57·46
Iron oxide (Fe_2O_3), alumina, and titanium oxide (TiO_2)	3·64	3·03	1·44	1·48
Calcic carbonate ($CaCO_3$)	73·80	90·33	27·90	39·26
Magnesic carbonate ($MgCO_3$)	0·75	0·95	0·30	0·36
Magnesic oxide (MgO)	..	..	..	..
Phosphoric anhydride (P_2O_5)	Traces	1·21	Trace	..
Soda (Na_2O) and potash (K_2O)	..	..	0·25	..
Ferrous carbonate ($FeCO_3$)	..	..	2·08	..
Sulphides and carbides	..	..	Trace	..
	100·00	99·38	99·83	100·00
Specific gravity	..	..	2·28	2·15

References.—K 2662 is a white siliceous limestone collected in January, 1909, from a sea-eroded face in a bay at the head of Perseverance Harbour.

K 2649, chalk, was found associated with clay, 2½ ft. below the surface, at Zircon Creek, 300 ft. above sea-level, at head of Perseverance Harbour.

K 2711 is a very hard light-grey rock, resembling flint, collected in January, 1909.

Prior's analysis will be found in "Petrographical Notes on Rock Specimens collected in Antarctic Regions during the Voyage of H.M.S. 'Erebus' and 'Terror,'" 1839–43. *Mineralogical Magazine*, vol. 12, p. 69, June 1898. (Title quoted from Aston). It represents a specimen of hard, compact, siliceous limestone from a "vein" in basalt, South Harbour (Perseverance Harbour), collected by McCormick.

OTHER OUTLYING ISLANDS.

No calcareous rock other than the soil and sand mentioned below seems to have been found in Bounty Island, Antipodes Island, Auckland Islands, or Macquarie Island.

On the south side of Enderby Island (one of the Auckland Group) there is a fine sandy beach half a mile in length, backed by dunes. The sands are very largely formed of comminuted shells, and a sample of beach-sand (J 826) analysed by Aston was found to contain 91 per cent. of calcium carbonate (1909, p. 762). A composite sample of

Enderby Island soil (J 823) was found by the same analyst to contain 45·16 per cent. of calcium carbonate, 1·68 per cent. of magnesium carbonate, and 1·95 per cent. of phosphoric anhydride. (See pp. 762 and 774 of publication cited below.)

The Kermadec Islands, situated about 600 miles north-east of Auckland, consist mainly of volcanic rocks. W. R. B. Oliver mentions the presence of "white calcite rock" on Dayrell and Chanter islets. This material should be examined in order to ascertain whether it is phosphatic or not.

The Cook Islands, which form a dependency of New Zealand, are not included in the scope of this bulletin. The same statement may be made concerning Samoa, which has recently been assigned to New Zealand by mandate under the Peace Treaty.

Literature.

The most important publication dealing with the outlying islands of New Zealand is "The Subantarctic Islands of New Zealand," published in two volumes by the Philosophical Society of Canterbury. On pp. 680–703 P. Marshall describes the geology of Campbell Island, and on pp. 703–4 that of the Snares. On pp. 705–44 R. Speight describes the geology of the Auckland, Bounty, and Antipodes islands. The soils, &c., are described by B. C. Aston on pp. 745–77. Numerous analyses are given.

Hector describes the geology of the outlying islands in Trans. N.Z. Inst., vol. 2, 1870, pp. 176–83, and vol. 28, 1896, pp. 736–38.

Casual references to the geology of Macquarie Island are contained in "The Home of the Blizzard" (by Douglas Mawson), vol. 2, 1915, pp. 167–254 (written by W. F. Ainsworth).

The papers by Marshall, Speight, and Aston cited above give full references to other geological literature dealing with the subantarctic islands. W. R. B. Oliver describes the geology of the Kermadec Islands in vol. 43, Trans. N.Z. Inst., 1911, pp. 524–35. On page 535 he gives a list of previous publications referring to their geology.

APPENDIX TO CHAPTER III.

At a late stage in the writing of this bulletin the writers were able to consult a copy of "Reports and Awards of the Jurors, N.Z. Exhibition, 1865," published at Dunedin for the Commissioners by Mills, Dick, and Co., 1866. The principal portions of geological or mining interest are the reports of the jurors in Class I (Mining, Quarrying, Metallurgy, and Mineral Products), pages 1–39; in Class II (Chemical Substances and Products, &c.), pages 40–43; in Class IXb (Gold and other Mining Machinery, &c.), pages 167–71; and Appendix A (Supplementary Report on Class I, by James Hector and William Skey), pages 371–458. See also pages 251–67 (geological specimens, &c.). On page 310 the following remarks are made with reference to pottery materials, &c.: "There is a great want of information concerning the clays and argillaceous earths of New Zealand, and it is to be regretted that the Exhibition has done little or nothing towards supplying this information. The Local Committees have generally confined themselves to simply securing specimens for exhibition, forgetful that *the value of the exhibits largely depends on the extent of the information afforded concerning them.*" These remarks, with very slight modification, stand good to-day, fifty-three years after they were first penned. They are quoted here on account of their being just as applicable to limestones as to pottery materials.

It is to be regretted that the very valuable Appendix A in particular cannot here be reproduced, but the greater part of the material in the Jurors' Reports relating to limestones and other calcareous rocks is summarized below :—

Pages 31–33 : Mention of various limestones, under the heading of "Building-stone."

Page 256 : Calcite, various parts of Canterbury ; travertine, Weka Pass ; marble and supposed dolomite,* Malvern Hills ; stalactite, &c., Mount Somers ; aragonite, Banks Peninsula.

Page 262 : Travertine, &c., Otago. (See also p. 392.)

Page 263 : Limestone, Lake Wakatipu and Green Island ; cement-stones, Moeraki, &c.

Pages 391–94 : The marbles exhibited include specimens from the west coast of Otago and from Nelson. Specimens of compact subcrystalline limestone come from the Kakanui Mountains, Lake Wakatipu, and Dun Mountain, Nelson. The limestones show great variety in composition and degree of usefulness. Many of them pass into calcareous freestones, and are more adapted for use as building-material than for the manufacture of quicklime.

The samples of limestone described by Hector and Skey will perhaps be most conveniently mentioned in the order adopted by them, which depended on the degree of purity. They are as follow :—

No. 1 : Limestone, Southland (no catalogue number or exhibitor's name). A high-grade, homogeneous, crystallized, jointed, white limestone, evidently of Tertiary age. $CaCO_3$, 98·80 per cent.

No. 2 : Limestone (Cat. No. 1204), exhibited by J. Hill, Winton. Faint-yellow, compact, crystallized limestone. $CaCO_3$, 97·90 per cent.

No. 3 : Supposed dolomitic limestone from Malvern Hills, but found to be nearly pure limestone. $CaCO_3$, 97·01 per cent.

No. 4 : Fossiliferous limestone (737)† from Oamaru. Compact light-yellow rock. $CaCO_3$, 95·95 per cent. This stone is very largely employed by Mr. D. Hutchison ("Hutchinson" is probably the correct spelling—see also p. 32) for burning into lime. It "does not occur in regular beds, but as dislocated and concretionary masses intermixed with quantities of worthless rock." The stone is also stated to be a "product of metamorphism," owing to alteration by volcanic rocks, but the meaning of this somewhat incorrect statement is not very clear.

No. 5 : Limestone, Wairoa, Auckland. A hard close-grained stone ; colour light-buff, mottled with black grains. $CaCO_3$, 95·47 per cent.

No. 6 : Lithographic limestone, Oamaru (737). A very fine smooth-grained stone, hard and compact, colour yellow, fracture conchoidal. $CaCO_3$, 95·18 per cent. Is obtained from concretions in the limestone No. 4, which have been more highly altered, and is "often so intermixed with fragments of volcanic rock as to resemble a slag."

No. 7 : Travertine, Dunstan Gorge, Otago (737). Exceedingly porous, in part coloured yellow, but burns to a beautifully white stone. $CaCO_3$, 95·04 per cent.

No. 8 : Limestone, Maitai River, Nelson (304). Exhibited by Dun Mountain Company. A hard, compact, close-grained stone of bluish-grey colour ; fracture subconchoidal. $CaCO_3$, 94·88 per cent. Occurs on the west flank of the Dun Mountain. Can be "brought to the Port with great ease" by the Dun Mountain tramway.

No. 9 : Limestone forwarded by Thomas Ball, Mangonui (Manganui), Auckland. A very good limestone, intersected by numerous veins of calc-spar (calcite), hard and compact. $CaCO_3$, 94·37 per cent.

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* Not dolomite, but a limestone.

† Specimens numbered 737 are from the collections of the Otago Geological Survey.

No. 10: Granular limestone, Oamaru (737). "This is a more compact limestone from the same locality as No. 4 (Hutchinson's Quarry), but of a grey colour with a dash of yellow." $CaCO_3$, 93·42 per cent.

No. 11: Limestone exhibited by C. Basstian, Aparima, Southland (1202). Colour, fawn-yellow. Dressed surface rather incoherent. $CaCO_3$, 92·20 per cent. A good sample of lime exhibited with this sample was made from similar stone.

Nos. 12 and 20: Fossiliferous limestone from Scinde Island, Napier. No. 20 was of a greyish colour, and tolerably compact; $CaCO_3$, 81·10 per cent. No. 12 was similar-looking stone, but more compact and of higher grade; $CaCO_3$, 91·80 per cent.

No. 13: Limestone, Lake Wakatipu (737). A hard very compact grey stone of considerable purity. The impurities are principally well-rounded black grains of sand, along with iron-pyrites and traces of "bituminous matter." $CaCO_3$, 91·60 per cent. "From the fossils it contains this limestone certainly belongs to the Lower Tertiary series, but it has undergone considerable alteration, so that it resembles a limestone of a more ancient date."

No. 14: Blue limestone, Kakanui Range (737). $CaCO_3$, 90·99 per cent. Hector and Skey's remarks deserve full quotation. They are as under: "Several blocks of this stone were exhibited by Mr. D. Hutchison [? Hutchinson], some of which were squared and partly polished. It is a compact bluish subcrystalline limestone, the most ancient, and probably the best, of any yet discovered in the province. It breaks into large rectangular blocks which sometimes appear as if laminated, from the occurrence of narrow parallel stripes of a dark-blue colour. Some of the beds are, however, truly fissile, and break into splinters. The weathered surface is gritty and harsh to the touch; its fracture is angular, and it is traversed by numerous veins of calc-spar. It forms a lenticular mass or stratum several hundred feet in thickness, interstratified with the slates of the Kakanui Range. Its outcrop can be traced in a north-west direction at least five miles. Wide flat valleys penetrate the limestone range, having a very gentle slope to the Shag Valley Plain, so that quarries could be opened in very accessible positions. It is of a quality that will render it of great value for burning into quicklime; and brown coal sufficiently good to be used as fuel for this purpose could be obtained within a few miles. If this limestone could be quarried in large blocks it would form a highly durable and ornamental building-stone, as it possesses all the properties of blue marble, and is susceptible of a high polish."

No. 15: Shelly limestone, Southland. The sample was a large mass, varying considerably in different parts, but generally possessed of sufficient coherence to form a good building-stone. $CaCO_3$, 90·80 per cent.

No. 16: Square blocks of granular limestone or "white freestone." Forwarded by Oamaru District Committee (517). This stone is very abundant, and of a beautiful white colour. $CaCO_3$, 90·14 per cent. Some specimens are very incoherent, others are more compact, but all work freely and harden afterwards. It is decidedly the most useful building-stone yet discovered in New Zealand.

No. 17: Conglomeratic limestone, three miles and a half south of Oamaru (737). A hard compact yellowish-white stone. $CaCO_3$, 87·08 per cent.

Nos. 18 and 19: Limestone from Otago Peninsula, forwarded by Mr. McDonald (737). No. 18 is dark-coloured, and contains 86·80 per cent. of calcium carbonate. No. 19 is yellowish, and contains 81·10 per cent. of calcium carbonate. It comes from a bed underlying the dark-coloured limestone. The yellow stone contains a rather large amount of yellow and black fine-grained sand.

Two other samples—a dark and a brown variety—gave to a partial analysis 14·20 and 18·20 per cent. of insoluble matter respectively, and both readily burnt to pretty good quicklime (see also Peninsula County).

The following table of limestone-analyses is a copy of that given on page 448 of the Jurors' Reports (analyses by W. Skey) :—

TABLE V.—LIMESTONES IN THE ORDER OF THEIR PURITY.

No.	Character.	Locality.	Specific Gravity.	Carbonate of Lime.	Carbonate of Magnesia.	Soluble Silicia.	Oxide of Iron.	Alumina.	Insoluble Matter.	Colour.	Remarks.
1	Crystalline ..	Southland ..	..	98·80	Trace	Trace	..	1·20	1·20	White ..	..
2	,, ..	,, ..	..	97·90	,,	,,	Trace	0·60	1·50	Bluish ..	..
3	Subcrystalline ..	Canterbury ..	..	97·01	1·19	,,	0·60	..	1·20	,, ..	..
4	Fossiliferous ..	Oamaru, Otago ..	..	95·95	2·17	0·6	Trace	0·45	0·74	Light yellow	..
5	Compact ..	Wairoa, Auckland ..	..	95·47	Trace	†	,,	2·29	2·24	Light buff ..	(*a*)
6	Lithographic ..	Oamaru, Otago ..	2·667	95·18	1·29	†	0·47	1·20	2·33	Yellow ..	(*b*)
7	Travertine ..	,,* ,, ..	..	95·04	2·56	Trace	..	0·60	1·80	Grey & yellow	..
8	Compact ..	Nelson	..	94·88	0·52	†	Trace	1·20	3·40	Bluish-grey ..	..
9	Veined ..	Auckland	..	94·37	0·23	†	1·60	Trace	3·80	Grey ..	..
10	Granular ..	Oamaru	..	93·42	2·58	0·50	Trace	1·01	2·45	,, ..	..
11	,, ..	Southland ..	..	92·20	Trace	†	2·20	Trace	5·60	Fawn ..	..
12	Shelly ..	Napier	..	91·80	0·60	†	1·40	,,	6·20	Grey ..	..
13	Compact ..	Wakatipu Lake, Otago	2·702	91·60	2·94	0·20	0·84	,,	4·42	,, ..	..
14	,, ..	Oamaru, Otago ..	2·698	90·99	2·16	3·10	0·62	,,	2·90	Bluish ..	(*c*)
15	Shelly ..	Southland ..	..	90·80	Trace	†	†	2·29	6·89	Grey ..	..
16	Granular ..	Oamaru, Otago ..	..	90·14	..	0·46	0·54	1·54	7·14	White ..	(*d*)
17	Conglomerate ..	,, ,, ..	2·583	87·08	Trace	†	0·79	2·85	8·58	Nearly white	(*e*)
18	Compact ..	Portobello, Otago ..	..	86·80	,,	†	Trace	0·80	12·40	Dark ..	..
19	,, ..	,, ,, ..	..	81·10	1·70	†	0·60	Trace	16·60	Yellowish ..	..
20	Shelly ..	Napier .. ,, ..	.	81·10	0·90	†	1·80	,,	16·20	Grey ..	.

* The locality, according to page 392, is Dunstan Gorge. † Not estimated. (*a*) Hygroscopic water, 0·80. (*b*) Trace of sulphate. (*c*) Loss, 0·23. (*d*) Loss, 0·18; tr. chlorides. (*e*) Loss, 0·78; tr. chlorides.

Pages 399–402: Specimen No. 11, under the head of "freestones," is an impure concretionary limestone from vicinity of Dunedin, exhibited by Hugh Calder, Caversham. $CaCO_3$, 68·51 per cent.

No. 12 is a calcareous sandstone from Weka Pass. $CaCO_3$, 65·96 per cent.

No. 13, calcareous sandstone from Oyster Point, Upper Harbour West, Otago (Harbour), is a hard dark-grey stone, seen to advantage when the tide is out. It also forms the upper part of a cliff, where it is not so hard. $CaCO_3$, 64·60 per cent.

No. 14: An impure siliceous limestone from Pleasant River, six miles from Waikouaiti. $CaCO_3$, 63·08 per cent.

No. 15: A calcareous freestone, Cornish Mount, Waikouaiti. Resembles No. 14. $CaCO_3$, 65·77 per cent.

No. 16: Calcareous sandstone, Waihemo. Light-coloured incoherent stone. $CaCO_3$, 61·60 per cent.

No. 17: Freestone from Kaikorai Valley. Finer-grained and more compact than the usual type of Caversham sandstone. $CaCO_3$, 60·86 per cent. The specimen was taken from the bed of the Kaikorai Stream about a quarter of a mile below the old lime-kiln quarry.

No. 18: Impure limestone from Sibbald's Quarry, Caversham Valley. Impurity is quartz-sand, with a little mica and clay. $CaCO_3$, 51·22 per cent.

No. 19: Calcareous sandstone from Hawksbury. Contains a considerable quantity of magnetic blacksand and some mica. $CaCO_3$, 50·05 per cent.

No. 20: Calcareous sandstone, Tokomairiro (Milton), is very coherent, close-grained, moderately hard, and of bluish-grey colour. Has the appearance of a compact basalt, and on page 451 is called "Mount Hacket basalt." Insoluble matter appears to be composed of rounded grains of quartz and olivine. $CaCO_3$, 41·20 per cent. Hector and Skey mention that this rock is used as a road-metal, and is in places fossiliferous.

No. 21: Building-stone, Kaikorai Quarry (see also No. 17). Similar to upper beds of Caversham sandstone, and contains a large percentage of yellow-coloured clay. $CaCO_3$, 40·45 per cent.

No. 22: Calcareous sandstone, Auckland, forwarded by His Honour the Superintendent. A hard and very compact stone; colour, mottled black and red. $CaCO_3$, 37·60 per cent.

No. 23: Freestone, Motupipi, Auckland, forwarded by His Honour the Superintendent. A moderately hard green-coloured stone, with black particles interspersed through its mass. $CaCO_3$, 30·27 per cent.

No. 24: Calcareous freestone, Moeraki. A rough block of mottled white and red freestone, very porous and absorbent of water. $CaCO_3$, 20·40 per cent.

Full analyses of the above fourteen stones appear in a table on page 451 of the Jurors' Report. The analyses are presumably by W. Skey (see p. 371).

On page 449 is a table containing six analyses of calcareous sandstones, which Hector and Skey (p. 396) state is taken from the reports of the Government survey of Otago, 1864, p. 125. The analyses represent three samples from Kaikorai (42·1, 62·8, and 68·5 per cent. of $CaCO_3$ and $MgCO_3$), the third sample being queried, one from Caversham (53·0 per cent. $CaCO_3$ and $MgCO_3$), one from Hawksbury (51·7 per cent. $CaCO_3$ and $MgCO_3$), and one from Pleasant River (64·1 per cent. of $CaCO_3$ and $MgCO_3$).

On pages 420–21, under the heading of "Hydraulic Cements," the results of an examination of Moeraki "boulders" are stated. The two analyses given are quoted on page 252 of this bulletin, but in a somewhat different form and with particulars varying from the original statements, which are essentially as follow:—

	(1)	(2)
Soluble silica	0·80	..
Insoluble in acid (clay)	17·80	..
Sand	..	35·00
Clay	..	6·60
Alumina and ferric oxide	8·70	7·60
Carbonate of lime	72·40	50·80
Carbonate of magnesia	0·30	Traces
	100·00	100·00

References.—(1) Portion of boulder free from crystallized carbonate of lime. Very hard and compact; colour, mottled grey; specific gravity, 2·655; hygroscopic water, 0·60 per cent. Iron is present partly as carbonate.

(2) Sample from another boulder, similar in external appearance to No. 1, but not nearly so hard and compact. Colour of sample, yellowish.

INDEXES.

INDEX I.—LOCALITIES AND GENERAL.

NOTE.—A few unimportant names have not been indexed, and there are doubtless accidental omissions. In other respects the index is not quite complete. The expression "district, &c." after a name indicates that the town, village, or post-office of that name is included. Similarly the expressions "river, &c.," "stream, &c.," include the valley or watershed of the river or stream named.

A.

Abbey Rocks (Whangarei Co.), 49, 50, 51.
Abbey Rocks (Westland Co.), 229, 230, 231.
Abbot's Creek, 273.
Addison's, 187, 192.
Advice to readers, 2.
Age of earth, 24, 25–26.
Agriculture, importance of lime in, 2, 3, &c.
Agriculture, works on, 3 (footnote).
Ahikereru, 89.
Ahipara, 36.
Ahuriri Plain, 252, 258.
Ahuroa Road or Stream, 122, 123.
Air-slaked lime, 3, 7, 10.
Akaroa County, 238–39.
Akaroa district, harbour, &c., 238.
Akitio County, 150–52, 153.
Akitio district, &c., 151.
Akitio River or Valley, 146, 151.
Akuaku, 92.
Albany, 66, 68.
Albatross Point, 86.
Albert, Mount, 71.
Albert, Port, 63.
Albury, 245, 246, 248.
Alexandra (Vincent Co.), 266.
Alford Forest, 243.
Alfred River, 193, 194.
Alfredton, 153.
Algæ, calcareous, 3, 22, 23, 261.
Algæ, calcareous, analysis of, 23.
Allandale Coal-mine, 270.
Allanton, 272, 275.
All Nations Point, 193.
Alps, Southern, 195, 211, 224, 232, 239, 241, 244, 245, 251.
Alumina, 14.
Ammonia liberated by lime, 3, 6.
Amodeo Bay, 75.
Amuri Bluff, 204, 205, 238, 269.
Amuri County, 195–97.
Amuri limestone, 92, 160, 198, 202, 203, 204, 206, 218, 219, 220, 221, 222, 223, 232, 234, 235, 236.
Analyses—
    Chemical, 4, 5, 7, 12–14, 16, &c.
    Compilation of, 30.
    Defects of some, 38.
    Limestone. (*See* under the various counties.)
    Qualitative, 16.
    Quantitative, 16.
    Summation of, 12.
Anatoki River, 170.
Anita Bay, 258, 259.
Anthony Creek, 74, 75.
Antipodes Island, 290, 291.
Aohanga, 151.
Aohanga River, 146, 151.
Aorangi Plain, 111.
Aorere River, &c., 164, 168, 169.
Aorere Series, 164.
Aotea Harbour, &c., 79, 83, 86, 87, 105.
Aparima River, &c., 279, 280, 293.
Apatite, 18.
Apiti, 137, 138.
Aponga, 46.
Aragonite, 16, 18, 75, 282.
Arapawa Arm (Kaipara Harbour), 61.
Arapohue, 56, 57, 58.
Arenaceous limestone, 13, 17, 18, &c.
Argillaceous limestone, 17, 18, &c.
Aria, 102, 106.
Arno, 249.
Arnott Point, 230.
Arnott Range, 224, 230, 231.
Arotoro Stream, 44.
Arrowtown, 263.
Arthur, Mount, 171, 175, 184, 192.
Arthur's Pass, 233.
Ashburton County, 238, 239, 241–45, 246.
Ashburton district, &c., 243, 244.
Ashburton River, 241, 242.
Ashhurst, 143, 144.
Ashley, 236.
Ashley County, 235–36.
Ashley, Mount, 235.
Ashley River, 233, 235, 237.
Ashley-Clinton, 138, 140.
Auckland, City of, 70, 71, 291, &c.
Auckland Harbour, 66, 70, 71.
Auckland, old Provincial District of, 292, 294, 295, &c.
Aurum, Mount, 260.
Avoca (Hobson Co.), 82.
Awahei Stream, 45.
Awakari Stream, 188.
Awakino County, 99–102, 106, 115, 116, 118.
Awakino district, &c., 99, 101, 106, 117.
Awakino River, &c., 99, 102.
Awakino Road, lower, 100.
Awakino Valley Road, upper, 101.
Awanui (Waiapu Co.), 92.
Awanui Heads or Harbour, 37, 38, 40.
Awaroa, near Huntly, 12, 82.
Awaroa Creek (Whangarei Co.), 50.
Awaroa Stream (Kawhia Co.), 85, 86, 87.
Awarua or Big Bay, 224, 230, 259, 263.
Awaruite, 264.
Awatere (Waiapu Co.), 92.
Awatere County, 181, 183, 197–203, 204, 206, 218.
Awatere River, &c., 182, 197, 198, 199, 202, 203.
Awatoetoe, 157, 158.
Awatunu, 127.
Awhea or Owhea River, 160.

B.

Back or Omanu Creek, 187.
Bacteria, 21, 22, 35.
Bacteria, nitrifying, 35.
Bagging lime, &c., 8.
Bainham, 165, 167, 168, 169.
Balclutha, 288.
Balfour, 282, 283.
Ballance district, &c., 147, 149, 150.
Balmoral, 196.
Banks Peninsula, 238, 239, 292.
Bannockburn Creek or township, 265.
Barewood, 275.
Barn Bay, 230, 231.
Barrier County or Island, 73–74.
Barrier Island, Little, 73, 74.
Barrier Range, 259, 263.
Barrytown, 212.
Basins, intermontane, 195, 217, 232, 241, 264.
Basins, intermontane, origin of, 195, 241, 264.
Batley River, 61, 62.
Baton River, 177.
Bay of Islands, 44, 47.
Bay of Islands County, 42, 43 44–48.
Bealey River, 232.
Beaumont, 285, 287.
Bedding of strata defined, 26.
Belgrove, 179.
Benmore, 198.
Ben Nevis, 177.
Berlin's Bluff, 187.
Bickerstaffe, 58.
Big or Awarua Bay, 224, 230, 259, 263.
Big Hill, 252.
Big Hill Track, 186, 189.
Big Muddy Creek, 69.
Big River (Collingwood Co.), 167.
Big River (Inangahua Co.), 211.
Big Wanganui district, &c., 231.
Big Wanganui River, &c., 224, 231.
Birchfield, 191.
Birchwood Station, 281.
Black Head (Taieri Co.), 273.
Black Point (Waitaki Co.), 252.
Black Rat Mountain, 185.
Blackball, 215, 216.
Black-birch Creek, 182, 202.
Blacktopp Creek, 189.
Blackwater Creek (Grey Co.), 213, 215.
Blackwater River (Buller Co.), 187.
Blackwater River (Inangahua Co.), 211.
Blairich Creek, 182, 202.
Blairlogie, 157.
Blakeney Point, 38, 40.
Blanket Bay, 271.
Blenheim, 181, 182, 183, 197, 203.
Bligh Sound, 280.
Blind or Tasman Bay, 180.
Blowhard, Mount, 111.
Blue Bottom (claystone), 216.
Blue Duck Creek, 187.
Blue Mountain (Waihemo Co.), 268 (footnote), 269, 270.
Blue Mountains (Tuapeka Co.), 285.
Blue Rocks, 177.
Blueskin or Waitati Bay or Harbour, &c., 271, 273.
Bluff Harbour, &c., 283, 284, 290.
Bluff Hill (Hawke's Bay Co.), 112.
Bluff Peninsula, &c., 281.
Bluff River (Awatere Co.), 201, 203.
Blyth River, 218.
Boat Harbour (Peninsula Co.), 276.
Bob's Cove, 258, 259, 260, 263, 265.
Boby's Creek, 218, 236.
Bonn (Germany), 146.
Boundaries of counties, &c., 36.
Boundary Creek, 218.
Boundary Peak, 187.
Bounty Island, 290, 291.
Bowentown, 78.
Braemyle, near Waikari, 222.
Branch Creek (Coromandel Co.), 74, 75.
Branch River (Awatere Co.), 201.
Brancepeth district, 157, 158.
Bray Creek, 213, 215.
Breaker Bay, 162.
Bream Head, 56.
Brighton (Buller Co.), 192.
Brighton (Taieri Co.), 274, 275.
Brightwater, 179, 180.
Broken River, 232, 233.
Brothers, The Two, 442.
Brown Creek (Grey Co.), 216.
Brown Creek (Murchison Co.), 193.
Brown, Mount, 219, 235, 236.
Brown River (Collingwood Co.), 164.
Browning's Pass, 240.
Brown's Railway station, 281, 282, 283.
Bruce County, 265, 267, 285-87, 288.
Brucite, 15.
Brunner, Lake, 213, 217.
Brunner township, &c., 216.
Bryneira or Barrier Range, 259, 263.
Buller County, 171, 184–92, 194, 209, 212.
Buller Gorge, Lower, 191, 192, 211.
Buller River, &c., 186, 187, 191, 193.
Bullock Creek (Buller Co.), 188.
Bullock Creek (Westland Co.), 230.
Bull's, 136.
Bungapore, 168.
Burk Creek, 209.
Burley's or Berlin's Bluff, 187.
Burnett, Mount, 165, 169.
Burning or combustion, 12.
Burning limestone. (*See* Calcination.)
Burnside, 274, 275.
Burnt Hill, 234.
Bushcroft (Masterton Co.), 158.
Butler's Creek, 132.

C.

Cabbage Bay, 74, 75.
Cairn Range, 238.
Calcareous concretions. (*See* Concretions.)
Calcareous sinter, Calc-sinter. (*See* Travertine.)
Calcination of limestone, 7, 11, 12, &c.
Calcite, 13, 14, 16, 17, 18, 22, 75, 77, 78, 291, 292, &c. (*See also* Lime, carbonate of.)
Calcium (metal), 9.
Calcium carbonate, 11, &c. (*See also* Calcite; Aragonite; Lime, carbonate of.)
Calcium oxide, 9, 10, 13, &c. (*See also* Lime; Quicklime; Slaked lime.)
Calcium phosphate, 15, &c. (*See also* Phosphate.)
Calculation of calcium carbonate, &c., 41, 42.
Cambridge, 83, 88.
Camelback or Koiterangi Hill, 224.
Cameron's, 215.
Cameron's Look-out, 157.
Camp Bay, 42.
Campbell, Cape, 183, 198, 199, 202, 203.
Campbell Island, 289-90, 291.
Cannibal Gorge, 195.
Cannington's, 245.
Canterbury, North, 203, 204, &c.
Canterbury Plain, 218, 232, 234, 236, 237, 238, 239, 241, 243-44, 246, 248.
Canterbury, South, 246, 247, 250, &c,

Cape Brett, 47.
Cape Campbell, 183, 198, 199, 202, 203.
Cape Colville, 75.
Cape Colville Range, 84.
Cape Egmont, 128.
Cape Egmont Peninsula, 120.
Cape Farewell, 164.
Cape Foulwind, 12, 187, 188, 189, 190, 191, 192, 228.
Cape Foulwind lime-kiln, 190, 228.
Cape Kidnappers, 112, 113.
Cape Maria van Diemen, 37.
Cape Palliser, 160.
Cape Palliser Peninsula, &c., 160.
Cape Runaway, 90, 92.
Cape Terrace (near Kumara), 215.
Cape Turnagain, 141, 146.
Capleston, 209.
Carbon, 10, 11.
Carbon dioxide, 10, 11, 12, 13, 15, 19, 20, 21.
Carbon dioxide, action on limestone, 21.
Carbonate of lime. (*See* Lime, carbonate of.)
Carbonic acid, 20.
Carbonic-acid gas, 10, 20.
Carbonic anhydride, 10, 11, 12, 13, 15, 19, 20.
Cardrona Valley, &c., 262, 263.
Carswell's, 157.
Carterton, 159.
Cascade Point, 264.
Cascade River, 231.
Cass Railway-station, 233.
Cass Range, Mount, 218, 219.
Cass River, 232.
Castle Creek, 202.
Castle Hill (Marlborough Co.), 182, 202.
Castle Hill (Tawera Co.), 232, 233.
Castle Point, 156.
Castlepoint County, 150, 156–57.
Castle Rock (Wallace Co.), 279.
Caswell Sound, 278.
Catlin's River, &c., 288.
Cave (Mackenzie or Levels Co.), 246, 248, 249.
Cave Point, 188.
Cave Valley, 254.
Cavendish, 243.
Caversham, 272, 273, 274, 275, 294.
Caves, limestone, 21, 46, 50, 54, 86, 102, 105, 168, 188, 212, 214, &c.
Cement—
    Natural or hydraulic, 4, 51, 63, 252.
    Portland, 4, 38, 52, 63, 172, 173, 252, &c.
    Puzzolana, 4.
    Works, 51, 52, 54, 63, 64, 172, 277, 286.
Chalk, chalky limestone, &c., 17, 22, 23, 46, 58, 92, 199, 207, 234, 250, 254, 283, 289, 290, &c.
Chalk Range, 201.
Chalky Inlet, 278.
Chalky Island, 278.
Champion Mine Track, 179.
Champion River, &c., 178.
Chancet, 199, 200.
Chanter Islets, 291.
Charleston, 188, 191, 192.
Charming Creek, 186.
Charwell River, 203.
Chatham Islands, 291.
Chemical analyses, 12–16. (*See also* Counties.)
Chemical equations, 10, 11, &c.
Chemist, knowledge and skill required by, 16.
Chemistry of lime and lime compounds, 9–12.
Chertsey, 244.
Cherwell River, 203.
Cheviot County, 206–7.
Cheviot district, &c., 206, 207.
Cheviot Estate, 206, 207.
Cheviot Hills, 206.
Chlor-apatite, 18.
Christchurch, 204, 207, 223, 236, 238, 239.
Cipollino, 259, 278.
Cirripedes, 36, 69.
Clarence River, &c., 197, 198, 201, 202, 203, 204, 205.
Classification, geological, 24, 25.
Clear Creek (Grey Co.), 213, 215.
Clevedon, 72.
Clifden, 279, 280.
Clifford Bay, 198, 203.
Clifton (Collingwood Co.), 173.
Clifton County, 99, 101, 102, 115–17, 119, 124.
Clinton, 288.
Clutha County, 288.
Clutha River, 264, 265. (*See also* Molyneux.)
Clyde (Vincent Co.), 264, 266.
Clyde (Wairoa Co.), 109, 110.
Coal, 79, 85, 99, 102, 115, 118, 164, 174, 184, 192, &c.
Coal Burn, 278.
Coal Creek (Ashburton Co.), 242.
Coal Creek (Westland Co.), 227, 228, 229.
Cobb, Mount, 184, 192.
Cobb River, 171.
Cobden, 212, 213.
Cobden limestone, 212, 213, 216, 226, 228.
Colbeck's Landing, 60, 62.
Coleridge, Lake, 240, 242.
Collingwood County, 164–70.
Collingwood district, &c., 164, 165, 168, 169.
Collophane, 15, 18–19.
Combustion or burning, 9, 12.
Concretions—
    Calcareous, 17, 19, 22, 36, 41, 43, 63, 71, 86, 92, 94, 112, 119, 132, 139, 161, 205, 216, 252, 256, 295, &c.
    McKay's definition of, 17.
    Siliceous, 23. (*See also* Flint.)
Cone-in-cone limestone, 36, 41, 63, 92, 112, 205, 252, &c.
Conical hills, 119, 127, 129.
Connelly's Creek, 227.
Conn's Creek, 191.
Constant Bay, 191.
Conway River, 195, 203, 204.
Cook County, 93, 95, 96–98.
Cook Islands, 291.
Cook, Mount, 245, 246.
Cooper's Island, 278.
Copper-mine (Kawau Island), 64, 65.
Copperstain Creek, 170.
Coral rock, 17, &c.
Corals, coralline limestone, 16, 17, 18, 22, 52, 79, 89, 94, 132, 208, 242, &c.
Corbyvale, 185, 186, 191.
Corinth or Koroniti, 132.
Cornish Mount, 271, 294.
Coromandel County, 74–76.
Coromandel district, &c., 74, 77.
Coromandel Range, 84.
Counties. (*See* under names—Mangonui, &c.)
County boundaries, &c., 36.
Courtney, Mount, 187.
Cove, The (Waipu district), 54.
Coverham, 201.
Croixelles Harbour, &c., 177, 178, 179, 181.
Cromwell, 263, 264, 266.
Cronin or Cornish Mount, 271, 294.
Crown Terrace, 263.
Croydon, 282, 283.
Crushington, 208.
Culverden, 196.
Curiosity Shop, 240, 241.
Curtis Point, 62.
Cyanide process, use of lime in, 4.

D.

Dairy Flat, 66.
Dannevirke County, 139, 141, 142–43, 146.
Dannevirke district, &c., 143.
Dansey's Pass, 257, 266 (footnote).
Dargaville, 44, 56, 57, 58.
Dart River (Awatere County), 201.
Deborah, 253, 257.
Deborah stone, 253. (*See also* Hutchinson Quarry stone.)
Dee River, 201.
Deep Creek (Inangahua Co.), 208.
Deep Creek (Grey Co.), 213, 215.
Definitions, 9, 26.
Denniston, 191, 192.
Denudation of land, 20, 21, 22, 23.
Devil disintegrator, 40.
Devonport, 66.
Dip, definition of, 26.
Dipton, 279.
Disintegrator, Devil, 40.
Division Hill, 196.
Dog Hills, 196.
Dolomite, dolomitic limestone, &c., 4, 18, 19, 103, 165, 166, 167, 169, 267, &c.
Dome, The, 283.
Domett (Cheviot Co.), 206, 207.
Domett, Mount, 184, 192.
Donald, Mount, 219, 236.
Donnelly Creek, 226, 227, 228, 229.
Doubtless Bay, 36.
Douglas, 121, 124.
Dowling Bay, 271, 272.
Drain Creek, 185, 189.
Drummond's Run, 177, 180.
Dry River, 171, 173, 174.
Dun Mountain, &c., 178, 179, 249, 292.
Dunback, 266, 267, 268, 269, 270, 273.
Dunedin, 257, 273, 275, 277, 286.
Dune sands, calcareous, 37, 40, 290.
Dunes, sand, 26, 37, 40, 85, 89, 135, 140, 146, 147, 152, 162, 163, 164, 197, 290, &c.
Dunmore, 114.
Dunollie, 226.
Dunstan Gorge, 265, 292.
Duntroon, 253, 255, 258.
D'Urville Island, 181.
Dusky Sound, 278.

E.

Earth, age of, 24, 25–26.
Easson's, 214.
East Cape, 92.
East Taupo County, 108–9.
Eden County, 71.
Eden, Mount, 71.
Edievale, 288.
Egmont, Cape, 120, 128.
Egmont County, 127–28.
Egmont, Mount, 119, 120, 124, 127, 128, 129, 134, 137.
Egmont Peninsula, Cape, 120.
Eketahuna County, 150, 151, 152–24.
Eketahuna district, &c., 152, 153.
Electricity, electric power, &c., 9, 231.
Elevation, The, 182.
Ellesmere County, 241.
Ellis Creek, 171.
Eltham County, 128–29, 133.
Eltham district, &c., 128.
Enderby Island, 290, 291.
Enner Glynn Creek, 179.
Equations, chemical, 10.
Erewhon, 136.
Esk River (Hawke's Bay Co.), 112.
Esk River (Tawera Co.), 232, 233.
Eyre County, 237.
Eyre River, 234.

F.

Fairfax, 279, 280.
Fairlie, 245, 246, 249.
Falls Creek, 185, 189.
Fanning's Cove, 278.
Fanny Bay, 278.
Featherston County, 158, 160–62.
Featherston district, &c., 161.
Feilding, 137, 143, 147.
Fern Flat, 193.
Ferniehurst, 204.
Few's or Twelve-mile Creek, 259.
Fifteen-mile Creek, 167, 169.
Fineness of pulverized limestone, 7–8.
Fiord County, 277–78, 279.
Fireball Creek, 212, 215, 217.
Fish, fossil, 52.
Fisherman Creek (Waitemata Co.), 67.
Fisherman Creek (Awatere Co.), 198, 199.
Fitzgerald Creek, 210, 216.
Flat Creek, 176.
Flat Point, 158, 159.
Flat-top Hill, 255, 257.
Flaxbourne River, 195, 197.
Fletcher Brook (Buller Co.), 186, 190, 191.
Fletcher Creek (Inangahua Co.), 209.
Flint, 23, 63, 160, 198, 201, 204.
Fluor-apatite, 18.
Folding of strata, &c., 21, 23.
Forest Hill Range, &c., 281, 283.
Fortrose, 284.
Fossil Point, 64.
Fossils, 24, 25, 52, 69, 103, &c.
Fossils, importance of, 25.
Foulwind, Cape, 187 *et seq.*, 228.
Four-mile Stream, 188.
Four Peak Range, 246, 247.
Four Point Range, 238.
Fox Point, 259.
Fox River, 188, 191.
Fox's Farm (Cape Foulwind), 188, 190.
Foxton, 147, 152.
Franklin County, 71, 72, 73.
Frank's Knob, 238.
Frankton Flat, &c. (Lake Co.), 261, 262, 263.
Frankton Junction, 83, 88.
Franz Josef Glacier, 231, 232.
Frasertown, 109.
Friday, Mount, 219.

G.

Gabriel's Gully, 284.
Garry River, 235.
Gentle Annie Bridge (Kawarau River), 265.
Gentle Annie Point (Buller Co.), 186.
Gentle Annie Quarry (Cook Co.), 97.
Geological classification, 24, 25.
Geological systems and time-scale, 24–26.
Geological terms, definitions of, 26.
Geology of limestone, 20–26.
Geordie's Hill, 264.
George Sound, 280.
Geraldine County, 245, 246–48.
German Hill, 119, 120.
Giant's Shirt, The, 199.

Gibbston Flat, &c., 261, 262.
Gibraltar Rocks, 60, 62.
Gibson Creek, 171.
Gisborne district, &c., 89, 91, 95, 96, 97, 98, 114.
Glacial epoch, 24.
Glacial-like gravels, 273.
Glaciation, real or supposed, 134, 135, 273.
Gladstone, 159.
Gladstone Station (Awatere Co.), 202.
Glasseye Creek, 185, 189.
Glenburn, 158.
Glenhope, 180, 194.
Glenlee Station, 202.
Glen Massey, 88. (*See also* Te Akatea.)
Glenmore, 276.
Glenorchy, 263.
Glenrose homestead, 111.
Glentunnel, 240.
Globe Hill, 211.
Goat Hill, 178.
Gold, discovery of, in Otago, 285.
Golden Bay, 117, 120, 128, 129, 135, 169, 174.
Golden Cross, 77, 78.
Goodwood, 254, 269.
Gordon, 122, 123.
Gordon's Knob (Waimea Co.), 178.
Gordon's Pyramid (Takaka Co.), 170, 171.
Gordon's Valley (Waimate Co.), 250.
Gore, 283.
Gore Bay, 206.
Gore River, 204.
Gorge Hill, 285.
Gorge Railway-station, 144, 147.
Gorge River, 230.
Gouland Downs, 167.
Grahamtown, 53. (*See also* Onerahi.)
Granite Creek, 185, 189.
Grassmere, Lake, 197, 198.
Gray's Hill Quarry, 96.
Great Barrier Island, 73-74.
Green Island, 273, 292.
Green Islets, 278.
Green Valley, 269.
Greenburn, 203.
Grey County, 184 (footnote), 188, 211–17, 224.
Grey, Mount, 235, 236.
Grey River (Awatere Co.), 202.
Grey River (Grey Co., &c.), 193, 212, 214, 217.
Greymouth district, &c., 22, 211, 212, 213, 214, 217.
Greymouth quarries, 213, 214.
Greytown (Featherston Co.), 161.
Greytown or Allanton (Taieri Co.), 272, 275.
Gribben Flat, 226.
Grove Bush, 283.
Gunner River, 167.
Gypsum, 18.

H.

Hacket Creek, 178, 179.
Hakataramea district, &c., 251.
Hakataramea River, &c., 249.
Halswell County, 238–39.
Hampden, 252.
Hangawera Hills, 84.
Hangitiki, 102.
Hanmer district, &c., 196.
Hanmer Plain, 195.
Hapuku River, 203, 204.
Harbour Cone, 276, 277.
Harbour Cove (?) 276.
Harihari, 229 (footnote).
Harper River, 240.
Harper's Pass, 217.
Harris Range, Lake, 259, 263.
Hastings, 113.
Hatuma, 140.
Hauhangaroa Range, 107.
Hauraki Goldfield, 74, 76, 77.
Hauraki Goldfield, lime in rocks of, 77.
Hauraki Gulf, 74.
Hauraki Plain, 77, 84. (*See also* Piako.)
Haurangi Mountains, 160.
Hautapu Hill, 86.
Hautapu Valley, 135, 136.
Hautotara River, &c., 160, 161.
Hauturu district (Kawhia Co.), 85.
Hauturu (mouth of Awaroa, Kawhia Co.), 87.
Hauturu or Little Barrier Island, 73, 74.
Havelock North, 113.
Hawea Flats, 263.
Hawea Lake, 258, 264, 266.
Hawera County, 129–30.
Hawera district, &c., 129, 130.
Hawkdun Range, 266.
Hawke's Bay County, 111–15, 141, 143.
Hawke's Bay old Provincial District, &c., 89, 95, 113, 138, 140, 141, &c.
Hawkeston, 111.
Hawksbury or Waikouaiti, 271, 294, 295.
Hay or Slippery Creek, 72, 73.
Hayes, Lake, 261, 262, 264, 266.
Heaphy River, 164, 167.
Heathcote County, 238–39.
Hedgehope, 282.
Helensville, 66.
Henley, 273.
Herangi Range, 99.
Herbert County, Mount, 238–39.
Herbert, Mount (Waipukurau Co.), 140.
Herbertville or Wainui, 141.
Herekino River or Harbour, 36, 43.
Hermitage, The, 246.
Heron, Lake, 241, 242.
Hewlett's Point, 52.
Hicks Bay, 91, 92.
High Peak, 239, 240.
Highfield Ridge, 196.
Hikurangi, 48, 49.
Hikurangi Mountain, 92
Hinds River, 242.
Hiruharama (Jerusalem), 132.
Hobson County, 56–58.
Hodson Brook, 211, 226, 227, 228, 229, 231.
Hohonu Settlement, 213, 215.
Hokianga County, 43–44.
Hokianga district, &c., 41, 42, 56.
Hokianga Harbour, 43, 44.
Hokianga South Head, 43.
Hokitika district, 211, 224, 225.
Hokonui Mountains, 281.
Holyoake Creek, 175, 176.
Home Creek, 233.
Homeburn, 161.
Hood Creek, 229.
Hooper's Inlet, 276.
Hope, 178.
Hope Saddle, 195.
Horahora, 49, 51, 56.
Horoeke, 43, 44.
Horowhenua County, 152.
Horrible, Mount, 249.
Horse Range, 252, 268, 270.
Hot Lakes district, 109.
Hoteo River, 63.
Huangarua River, 160.
Huia Stream, 185, 189.
Huiakama, 125.
Huiarau Range, 109.
Huiroa, 122, 124, 125.
Hukerenui, 47.
Hundalee, 204.

Hunt Creek, 209.
Hunter's Hills, 245, 246, 250, 251.
Hunterville, 135, 136.
Huntly, 12, 79, 81, 83, 84.
Hunua Range, 118.
Huruhuru (ravine), 105.
Hurunui, 222.
Hurunui flats, 206.
Hurunui Mound, 196.
Hurunui River, 217, 218, 219, 223.
Hurunui–Waiau basin or plain, 195, 196, 218, 219.
Hutchinson Quarry stone, 253, 255.
Hutchinson's Quarry, 255, 256, 257.
Hutt County, 162–63.
Hutt River, &c., 162, 163.
Hyde, 267.
Hydraulic or argillaceous limestone, 17, 36, 37, 38, 48, 58.
Hydrogen, 9, 10.
Hydrogen monoxide (water), 10.

I.

Ica homestead, 156.
Ida Valley, 266.
Igneous rocks, 24, 26, &c.
Igneous rocks, marble in, 24, 258.
Ignition, loss on, 15.
Inangahua County, 187, 208–11, 212, 216.
Inangahua Junction, 187, 191, 192, 195, 208 *et seq.*
Inangahua Junction, proposed lime-kiln at, 210.
Inangahua River, &c., 195, 208, 209, 211.
Inch Valley district, &c., 269.
Inch Valley Railway-station, 270.
Inchbonnie, 217.
Inglewood, 119.
Inland Kaikoura Mountains, 201.
Inland Road, New, 185, 186, 189, 190, 191.
Insoluble matter, 20, 38.
Intermontane depressions, 195, 217, 232, 241, 264.
Intermontane depressions, origin of, 195, 241, 264.
Interpretation of analyses, 12–14.
Introduction, 1.
Invercargill, 270, 280, 283, 284.
Iron or Koau Point, 91.
Iron oxides, 14–15.
Iron-pyrites, 16.
Isolated Hill, 196.
Italy, 244.

J.

Jackson's Bay, 224, 230, 231.
Jacob's or Aparima River, 279, 280, 293.
Jed River, 206.
Jerusalem or Hiruharama, 132.
Jordan River, 198.

K.

Kaeo district, &c., 41.
Kahaurangi Point, 164.
Kahutara River, 203.
Kaiapoi, 237.
Kaiata mudstone, 216.
Kaihu, 44, 58.
Kai-iwi district, &c., 132, 133.
Kai-iwi River, &c., 130, 131.
Kaikohe, 44, 46, 47.
Kaikora or Otane, 138, 139, 140.
Kaikora, misspelt Kaikoura, 140.
Kaikorai Valley, &c., 273, 274, 294, 295.
Kaikoura County, 198, 201, 203–6, 218, 269.
Kaikoura district, &c., 203, 204, 205, 238.
Kaikoura Mountains, 201.
Kaikoura Mountains, Inland, 201.
Kaikoura Mountains, Seaward, 195.
Kaikoura Peak (Opotiki Co.), 91.
Kaikoura Peninsula, 204, 205.
Kaikoura Plain, 203, 204.
Kaikoura Range (Opotiki Co.), 91.
Kaimanawa Range, 108, 135.
Kaimata (Taranaki Co.), 119.
Kaimata (Grey Co.), 212, 213.
Kaingaroa Plains, 108.
Kaipara district, 48, 56, 61, 62, 63.
Kaipara Flats, 63, 66.
Kaipara Harbour, 62, 63, 65, 70, 83, &c.
Kaipara River, 66.
Kairanga County, 144, 147–48.
Kairauwaru Bay, 37, 42.
Kairuru marble-quarry, 176.
Kaitaia district, &c., 37, 38, 39.
Kaitaki or Patua Range, 119.
Kaitangata Coal-mine, 287.
Kaitieke County, 118–19, 126.
Kaiwaiki, 132.
Kaiwaka, 61.
Kaiwhata River, 158.
Kaka, 177, 180, 194.
Kakahu Gorge, Valley, &c., 246, 247.
Kakanui district, &c., 254, 255, 257, 269.
Kakanui Range, 252, 266, 268, 269, 293.
Kakanui River, 253, 254.
Kakanui stone, 253.
Kakapo River, 185, 189.
Kakariki, 143.
Kakawau Peak, 212, 216, 217.
Kamo, 46, 48, 50.
Karamea Bend, 184.
Karamea district, &c., 186, 191, 192.
Karamea River, 184, 185, 191.
Karamu, 79, 80, 82.
Karangahake district, &c., 77, 78.
Karangahake – Te Aroha Range, 84.
Karatea, 132.
Kareponia, 40.
Karioi, Mount, 79.
Katikati Heads, 78.
Kaueranga River, 76.
Kaukapakapa, 66, 70.
Kaurihorehore, 49.
Kawakawa district, &c., 44, 45, 46, 47.
Kawarau Falls, 261.
Kawarau River, 265.
Kawau Island, 64–65.
Kawhia County, 85–87, 99, 102, 107, 118.
Kawhia district, &c., 79, 87, 105, 117, 128, 129.
Kawhia Harbour, 83, 85, 86, 87, 106, 120.
Kawhia limestone, 72 (footnote), 86, 106, 125.
Kekerangu, 183, 197.
Kennedy's Bay, 75.
Kereru, 112, 138, 140.
Kereru Stream, 142.
Kerikeri, 47.
Kermadec Islands, 291.
Kerosene Ridge, 157.
Kidnappers, Cape, 112, 113.
Kilns, lime, 7, 51, 63, 64, 87, 115, 122, 173, 187, 190, 210, 213, 214, 224, 225, 228, 242, 247, 257, 259, 268, 269, 270, 272, 276, 277, 282, 286.
Kingston, 260, 263, 282.
Kiore, 116.
Kioreroa, 54.
Kitty Creek, 171.
Kiwi Creek, 230.
Kiwitea County, 137.
Knoll Point, 213, 217.
Kohaihai Point, 164, 184.
Kohukohu, 43, 44.

Kohuratahi, 125.
Koiterangi district, 224, 225, 226, 228.
Koiterangi Hill, 224, 225.
Koiterangi limestone, 224, 226, 228, 230.
Kokatahi–Koiterangi Plain, 225, 230.
Komata Reefs, 78.
Komiti Peninsula, 61.
Kongahu Point, 186.
Konini waterworks, 149, 150.
Kopuarangi Stream, 186.
Koraka, 44.
Koroniti or Corinth, 132.
Koropupu, 87.
Kotiki Point, 91.
Kotuku, 22, 212, 213, 215.
Kowai County, 218, 219, 235, 236–37.
Kuaotunu (Whakatane Co.), 90.
Kumara, 215.
Kuripapanga, 111.
Kurow, 251, 252, 253, 258.
Kurow Stream, 252.
Kynnersley (Mokihinui mouth), 186.

L.

Lady Barkly Railway-station, 282.
Lake County, 258–64, 278.
Lake Harris Range, 259.
Lake-marl, 23.
Lakes—
  Brunner, 213, 217.
  Coleridge, 240, 242.
  Grassmere, 197, 198.
  Hawea, 258, 264, 266.
  Hayes, 261, 262, 264, 266.
  Heron, 241, 242.
  McKerrow, 263.
  Manapouri, 278, 279, 280.
  Moke, 260.
  Ohau, 252.
  Omapere, 43, 45.
  Pukaki, 258.
  Taupo, 88, 107, 108.
  Taylor, 217.
  Te Anau, 278, 279, 280.
  Wahi, 79.
  Waihola, 273.
  Waikare, 83.
  Waikaremoana, 89.
  Waipori, 273.
  Wakatipu, 259, 260, 262, 263, 265, 292, 293, 294.
  Wanaka, 262 *et seq.*
  Whangape, 79.
Lakes district, Hot, 109.
Lakes district, Cold. (*See* Lakes Wanaka, Wakatipu, Te Anau, &c. ; *also* Lake County.)
Land, elevation or depression of, 21, 22, 23, 24, 195, 241, 264, &c.
Landguard Bluff, 134.
Landing Bridge, 209.
Lankow Creek, 178, 180.
Lanky Creek, 208.
Lawrence, 284, 285, 287.
Lawrence Stream, 185, 189.
Leda marl, 73, 92.
Lee River, 178.
Lepperton, 119, 120.
Leslie River, 171, 184.
Levels County, 245, 246, 248–49.
Ligar Bay, 171, 172, 174.
Lignite, 85, 147, 148, 153, 156, 264. (*See also* Coal.)
Lillburn watershed, 279.
Lily Creek, 187.
Lime, 2 *et seq.*
  Air-slaked, 10.
  Amount of, required by soils, 3.
  As soil-dressing, 2, 3, &c.
  Carbonate of, 3, 5, 6, 7, 8, 11, 17, &c.
  Chemistry of, 9–12, 15.
  Compared with limestone, &c., 5–7.
  Definition of, 9, 15.
  Functions of, in agriculture, 3.
  Military importance of, 4–5.
  Minerals containing, 16–19, &c.
  Quick, 5, 6, 7, 8, 9, 10, 11.
  Reversion of carbonate of, 3, 7, 10.
  Slaked, 5, 6, 7, 10.
  Tests for, 19.
  Transport of, 8.
  Uses of, 3, 4, 5,
Limehills, 262, 282.
Limekiln Bay, 51.
Lime-kilns, 7, 51, 63, 64, 87, 115, 122, 173, 187, 190, 210, 213, 214, 224, 225, 228, 242, 247, 257, 259, 268, 269, 270, 272, 274, 276, 277, 282, 286.
Lime-works, &c., 8, 9, 51, 52, 63, 64, 87, 103–4, 114, 122, 154–55, 172, 200, 204, 220, 228–29, 242, 269–70, 281, 282, 287.
Limestone—
  Advantages of, 6–7.
  Age of, 26.
  Alteration or metamorphism of, 23, &c.
  As soil-dressing, 5, 6, 7, 8, 43, 68, 132, &c.
  Black, 286.
  Calcination or "burning" of, 7, 11, &c.
  Compared with quicklime, &c., 5–7.
  Constitution of, 13, 14–16.
  Definition of, 9.
  Friable or "soft," 22, 68, 149, 160, 199, 200, 202, 206, 219–20, 223, 247, 249.
  Geology of, 20–26.
  Hydraulic, 17, 36, 37.
  Impurities of, 5, 7.
  Lithographic, 37, 205, 229, 230, 280, 292.
  Machinery for pulverizing, 2, 7, &c.
  Magnesian, 4, 18, 94, 103, 165, 166, 167, 169, 267.
  Massive, 17.
  Mode of occurrence of, 23, &c.
  Origin of, 18, 20, 21, 22–23.
  Phosphatic, 7, 80, 81, 108, 219, 255, 256, 289.
  Plant for treatment of, 2, 7. (*See also* Lime-kilns; Lime-works.)
  Pulverized, 3, 5, 6, 7, 8, 49, 87, &c.
  Pulverized, fineness of, 7–8.
  Sampling of, 26–30.
  Solubility of, 20, 21.
  Tests for, 19–20.
  Transport of, 8, 11, &c.
  Uses of, 2, 4, 5.
  Weathering of, 7, 8, 22, 53, 199, 220, &c.
Limestone Bluff (Ashburton Co.), 242.
Limestone Bluff (Waimea Co.), 179.
Limestone Creek (Buller Co.), 188.
Limestone Diggings, 212.
Limestone Island, 51, 52, 53, 56, 63.
Limestone Point (Collingwood Co.), 166. 167.
Limestone Point (Kawau Island), 64.
Limestone Range, 242.
Limestone Valley, 248, 249.
Limestone-cliff Bay, 230.
Lindis Valley, 264.
Lisbon Creek, 212.
Literature, 30–34. (*See also* under each county heading.)
Lithographic limestone, 37, 205, 229, 230, 289, 292.
Little Barrier Island, 73, 74.
Little Ben Nevis, 178.

Little Pareora Stream, 250.
Little River, 238.
Little Totara River, 188.
Little Wanganui Head, 186, 189, 191.
Little Wanganui River, 185, 189, 191.
Little Wanganui district, 191.
Livingstone, 257.
Loburn, 235.
Lodes, calcitic, gold-bearing. (*See* Veins.)
Long Point, 109.
Longburn Junction, 147, 148.
Longwood Range, 279.
Lottery Creek, 195, 196.
Lovell's Flat, 287.
Lumsden, 279 (footnote), 280.
Lyell district, &c., 186, 187, 190, 195.
Lyttelton, 238.

M.

Mabel, 281.
Macandrew Bay, 276.
Maccoinnich, Mount, 206.
Mackenzie County, 245–46, 248, 250.
Mackenzie district, &c. (Cheviot Co.), 206.
Mackenzie Plain, 241, 245, 252.
McKerrow, Lake, 263.
Mackley Valley, 186.
McLeod's Bay, 51.
McMurray Creek, 187.
Macquarie Island, 290, 291.
Maerewhenua limestone, 253.
Maerewhenua River, &c., 253.
Magnesia, 15.
Magnesian concretions, 94, 95.
Magnesian limestone, 4, 18, 94, 103, 165, 166, 167, 169.
Magnesian marl, 267.
Magnesite, 167, 258, 278, 289.
Maharahara, 145.
Mahia Peninsula, 109.
Mahihinui Range, 105.
Mahoenui, 99, 100, 101.
Mahurangi, 63, 64, 65.
Maire Creek, 153.
Maitai limestone, 178 *et seq.*, 184, 197, 292.
Maitai River, &c., 178, 180, 292.
Maitai Series, 178, 232, 252. (*See also* Maitai limestone.)
Makahakaha–Ngarara Stream, 93, 94.
Makakahi Stream, &c., 148.
Makara County, 162–63.
Makara district, &c. (Makara Co.), 162, 163.
Makara Stream (Clifton Co.), 117.
Makaraka, 98.
Makaretu Gorge (Dannevirke Co.), 142.
Makaretu River (Wairoa Co.), 109.
Makatui Stream, 117.
Makino, 143.
Makotutu, 142, 143.
Makuri district, &c., 148, 149, 150.
Malcolm Creek, 178.
Malvern County, 237–38, 239, 241.
Malvern Hills, 237, 238, 240, 292.
Mamaku, 89.
Manaia, 129.
Manapouri Lake, 278, 279, 280.
Manawatu County, 146–47.
Manawatu Gorge, 137, 143, 144, 145, 147, 148, 157.
Manawatu River, 142, 143, 146, 147, 148, 152.
Mangahani Stream, 126.
Mangahao River, 148.
Mangahe, 142.
Mangahei, 142.
Mangaio, 126.
Mangakakia, 55.
Mangakotukutuku Stream, 75.
Manganui-a-te-ao River, 126.
Mangaokewa Stream, 104.
Mangaorongo Stream, 94.
Mangaotaki Stream, 101, 102, 107.
Mangapai, 49, 52.
Mangapakeha Valley, 157.
Mangapapa Stream, 95.
Mangapohue Road, 100, 106.
Mangapoike River, 97, 109.
Mangapu River, 105.
Mangapuaka, 142.
Mangara Creek, 86.
Mangarahu, 57.
Mangarapa, 104.
Mangataikapua Stream, 93, 94.
Mangatainoko Stream, 144, 148.
Mangatawa, 155
Mangatawa Stream, 94, 95.
Mangatoro Stream, 142, 144.
Mangatu River, 93.
Mangatuamaru Stream, 94.
Mangaweka, 137.
Mangawhare, 56, 57, 58.
Mangawhitikau Stream, 105.
Mangonui County, 36–40.
Mangonui or Monganui district, 36, 37, 292.
Maniototo County, 266–67.
Maniototo Plain, 266, 267, 273.
Mantell, Mount, 194.
Manuherikia Valley, &c., 265, 266.
Manukau County, 70, 71–72, 73.
Manukau Harbour, Heads, &c., 66, 69, 70, 73, 83.
Maori Gully (Buller Co.), 185, 189.
Maps, 36.
Maraetai, 71, 72.
Marahemu, 62.
Marakopa, 100.
Maratoto, 78.
Marble, 17, 23, 24, 42, 44, 152, 153, 161, 181, 193, 194, 229, 240, 246, 258, 259, 264, 265, 266, 267, 272, 277, 278, 283, 288, 289, 292.
Marble Creek, 175, 176.
Marble Point, 196.
Marl, &c., 17, 23, 41, 58, 65, 73, 90, 92, 111, 114, 139, 141, 216, 218, 261, 262, 264, 266, 267, 274, 275, &c.
Marlborough County, 181–83, 197, 202.
Marlborough old Provincial District, 198.
Marsden, 212, 213.
Martinborough, 161, 163.
Martin's Bay, 258, 259, 263.
Marton, 136, 137.
Maruia Plains, 193, 194.
Maruia River, &c., 193, 194, 195.
Mason, Mount, 219.
Mason River, 195, 196.
Masterton County, 157–58, 159.
Masterton district, &c., 152, 157, 158.
Mata River, 92, 96.
Mataikona River, 150.
Matakana Island, 85.
Matakitaki River, &c., 193, 194, 195.
Matakoau or Iron Point, 92.
Matakohe, 61, 62.
Matamata County, 88–89.
Matamata district, &c., 88.
Matapiro and Aorangi Plain, 111.
Matapouri, 131.
Mataroa, 135.
Matata, 90.
Mataura River, 281.
Matawai, 94.
Mathias Pass, 241.
Matiri River, &c., 193, 194.

- Maungaharuru Range, 111.
- Maungakaramea, 55.
- Maungapohatu Mountain, &c., 89, 90, 91.
- Maungaraki Range, 159, 160.
- Maungataniwha Range, 36.
- Maungatautari Gorge, 88.
- Maungaturoto, 58.
- Mauriceville County, 154–56.
- Mauriceville district, &c., 143, 145, 147, 149, 150, 152, 153, 155, 156, 158, 159, 163.
- Mauriceville limestone, 149, 154 *et seq.*
- Mead River, &c., 201, 202.
- Mechanically formed limestone, 22, &c.
- Medhury, 223.
- Meek's Quarry, Teaneraki, 255.
- Mendip Hills, 195.
- Mercer, 73, 83.
- Merrivale, 280.
- Methven, 244.
- Microscope, use of, 13.
- Middle Division Creek, 157.
- Middlemarch, 273, 275.
- Midhirst, 123, 124.
- Mikonui River, 226.
- Milhurn, 265, 267, 273, 275, 285 *et seq.*
- Milford Sound, 24, 258, 263, 278.
- Mill Creek, 180.
- Millerton, 192.
- Milton, 285, 286, 294.
- Miner River, 179, 194.
- Minerals, lime-bearing, 16–19.
- Minerals, rock-forming, &c., 13, 14, 16, 23, &c.
- Misery, Mount, 249.
- Mititai, 56, 57.
- Mitre Peak, 259.
- Moakuroroa or Moakurarua Stream, 102.
- Moana 217. (*See also* Brunner, Lake.)
- Moawhango, 111, 136.
- Moeangiangi, 112.
- Moeatoa Mountain, 99.
- Moeraki, 252, 292, 295.
- Moeraki boulders, 252, 268, 295.
- Moeraki Peninsula, 252,
- Mohakatino River, &c., 99, 115, 116, 117.
- Moisture, 10, 13, 15.
- Mokau district, &c., 101, 105, 115, 117, 125.
- Mokau limestone, 115, 116, 117, &c.
- Mokau-Mohakatino Block, 115, 117.
- Mokau River. &c., 85, 99, 101, 102, 106, 115, 116, 117, 118, 120, 128, 129.
- Mokauiti Stream, 106.
- Moke Lake, 260.
- Mokihinui Mine, 186, 191.
- Mokihinui Mouth, 186.
- Mokihinui Reefs, 186.
- Mokihinui River, 184, 185, 186, 189, 191, 192.
- Molyneux River, 264, 285, 287.
- Momoma, 65.
- Mongonui. (*See* Mangonui.)
- Moonlight Creek (Grey Co.), 216.
- Moonlight Creek (Lake Co.), 260.
- Moonlight Range, 279.
- Moore's Hill North, 218.
- Moore's Hill South, 218.
- Morere, 109.
- Morrinsville, 84.
- Morrison's Caves, 54.
- Mosgiel, 275.
- Mossburn, 280.
- Motatau, 46.
- Motu, 93.
- Motueka district, &c., 174, 177, 180.
- Motueka Plain, 175, 180.
- Motueka River, &c., 177, 180.
- Motuhora, 91, 93, 95, 98.
- Motunau River, 218, 219.
- Motupipi (Auckland), 295.
- Motupipi (Takaka Co.), 172, 174.
- Motupipi Island, 70.
- Motupipi River, 171, 172.
- Motutapu Island, 69.
- Motutara Point, 86.
- Moumoukai Mountain, 109.
- Mount or Mountain—
  - Alhert, 71.
  - Alexander Range, 219.
  - Arthur, 171, 175, 184, 192.
  - Ashley, 235.
  - Aurum, 260.
  - Black Rat, 185.
  - Blowhard, 111.
  - Brown, 219, 235, 236.
  - Brown beds, series, or limestone, 196, 223, 235, 236.
  - Cass Range, 218, 219.
  - Cohb, 184, 192.
  - Cook, 245, 246.
  - Cornish or Cronin, 271.
  - Courtney, 187.
  - Domett, 184, 192.
  - Donald, 219, 236.
  - Eden, 71.
  - Egmont, 119, 120, 124, 127, 128, 129, 134, 137.
  - Friday, 219.
  - Grey, 235, 236.
  - Herbert (Waipukurau Co.), 140.
  - Herbert County, 238–39.
  - Hikurangi, 92.
  - Horrible, 249.
  - Karioi, 79.
  - Maccoinnich, 206.
  - Mantell, 194.
  - Mason, 219.
  - Misery, 249.
  - Ngauruhoe, 118.
  - Owen, 175.
  - Parihaki, 50.
  - Peel, 170, 184, 192.
  - Percy Smith, 251.
  - Pirongia, 79, 80, 86, 103.
  - Potts, 243.
  - Rangitoto, 66.
  - Ruapehu, 118, 126, 134, 136.
  - St. Mary, 252.
  - St. Mary Series, 252.
  - Scarlett, 185.
  - Silverhorn, 260.
  - Smart, 101.
  - Somers, 242, 243, 292.
  - Tarawera, 89.
  - Thomas, 235.
  - Tongariro, 118.
  - Vernon, 139.
  - White, 232, 233.
  - White River, 232, 247.
- Mountains, Ranges. (*See above, and also* Southern Alps; Kaikoura; Kakanui; Horse; St. Arnaud; Pikikiruna; Rimutaka; Tararua; Ruahine; Huiarau; Tuhua, &c.)
- Moutere Hills, 174, 180.
- Mulligan Creek, 208.
- Murchison County, 192–95.
- Murchison district, &c., 193, 194, 195.
- Murray Creek, 208.
- Muzzle River, 201.

N.

- Nada Creek, 187.
- Napier, 98, 111, 112, 113, 143, 145, 293, 294.
- Napier limestone, 111.
- Narrows, The, 42.
- Nelson, &c., 174, 179, 180.

Nelson, old Provincial District of, &c., 137, 147, 152, 163, 292, 294.
Nemona, 215.
New Creek (Buller Co.), 187.
New Inland Road, 185, 186, 189, 190, 191.
New Plymouth, 87, 115, 120, 124, 128, 129.
New River (Grey Co.), 212.
New River Estuary (Southland Co.), 284.
Newhaven, 288.
Newlands, 140.
Newman, 153.
Newmarket, 171.
Newstead, 114.
Newton Flat, 193, 194.
Ngapara, 253, 255, 258.
Ngapipito, 46.
Ngarua quarry, 176.
Ngaruawahia, 88.
Ngaruhoe, Mount, 118.
Ngaruroro River, &c., 111, 112.
Ngawapurua, 145.
Ngunguru River, 52.
Nightcaps, 280.
Nikau (pa), 105.
Nile or Waitakere River (Buller Co.), 188, 191.
Nine-mile Bluff, 216.
Nitrification, 3.
Nitrifying organisms, 3, 5. (*See also* Bacteria.)
Nitrogen, 3, 5, 6.
Nokomai district, 283.
Nolan's quarry, 125, 130.
North Auckland. (*See* the various counties.)
North Canterbury, 203, 204, 237, 238, &c. (*See also* the various counties.)
North Cape, 36.
North Dean, 218.
North Otago. (*See* Waitaki County, &c.)
North Taranaki, 134. (*See also* Clifton County; Whangamomona County, &c.)
North Westland, 224. (*See also* Grey County; Westland County.)
North-east Valley, 257.
North-west Bay, 289.
Nuhaka, 110.
Nuhaka River, &c., 109.
Nukumaru district, &c., 128 *et seq.*, 137.
Nukumaru limestone, 130, 131–32, 133, 134.

O.

Oamaru Breakwater, 256.
Oamaru district, &c., 246, 252, 253, 256, 257, 258, 267, 273, 292, 293, 294.
Oamaru Gardens, 256.
Oamaru stone, 242, 253, 254, 255, 257.
Oaro Stream, 205.
O'Brien Creek, 178, 179, 180.
Objects of bulletin, 2.
Ohaeawai, 48.
Ohakune, 126.
Ohau, Lake, 252.
Ohau River, 152.
Ohinemuri County, 77–79, 83, 84.
Ohiwa Harbour, 90.
Ohura County, 117–18.
Ohura district, &c., 118.
Ohura Valley, 106.
Ohutu, 136.
Okahu (Hobson Co.), 58.
Okahu Stream (Whakatane Co.), 89.
Okahukura, 117, 120, 124, 125.
Okaihau, 45.
Okarito district, 231.
Okarito Forks, 231.
Okarito Lagoon, 231.
Okato, 119.
Okehu, 132.
Okuku River, 235, 236.
Okura Stream, &c., 68, 69, 70. (*See also* Redvale.)
Okuru, 231.
Omaka River, 182, 183, 202.
Omanu or Back Creek, 187.
Omapere, Lake, 43, 45.
Omega Stream, 94.
Omihi Valley, 218, 233.
Omoho Creek, 75.
Onairo, 117.
Onairo Series, 119, 121.
Onakaka Stream, 166.
Onehunga, 71.
Onerahi, 49, 53, 56.
Onewhero, 79, 81.
Ongarue River, &c., 106, 107, 117.
Oolite, oolitic limestone, 22, 215.
Opapa (Te Aute), 112.
Oparae Hill, 142, 146.
Oparau Valley, &c., 86, 87.
Open or Waipiro Bay, 92.
Opihi River, 245.
Oponae, 91.
Opotiki County, 90–91.
Opotiki district, &c., 90, 91.
Opouae (?), 91.
Opouawa or Opouawe Stream, 160.
Opua, 47, 56.
Opuatia district, &c., 81.
Opuha River, &c., 245, 247.
Opunake district, &c., 120, 127, 128.
Orangiwhao Hill, 86.
Orari River, &c., 246, 247.
Orbitolite limestone, 61.
Organic matter, 13, 15.
Organically formed limestone, 18, 23, &c.
Ormond, 96.
Ormond limestone, 96.
Ormondville, 142, 143, 145, 152.
Orongorongo Stream, 162.
Orotangi Cliff, 86.
Oroua County, 143–44.
Oruawhero Arm (Kaipara Harbour), 61, 63.
Oruru Valley, 36, 37.
Otago, Central, 267. (*See also* Maniototo County; Vincent County, &c.)
Otago Harbour, 271, 272, 273, 294.
Otago Peninsula, 272, 276, 277, 293. (*See also* Peninsula County.)
Otaharuru Creek, 111.
Otahe or Otehe Point, 80.
Otaika, 53, 54.
Otaio River, &c., 245, 250.
Otakaika. (*See* Otekaieke.)
Otaki district, 152.
Otaki River, 152.
Otamatea Arm (Kaipara Harbour), 61, 62.
Otamatea County, 58–62.
Otamauri Creek, 111.
Otane or Kaikora, 138, 139, 140.
Otaunui Valley, 118.
Otautau, 279, 280.
Otere Stream, 165.
Otira, 213, 217.
Otira Tunnel, 233.
Otiria, 47.
Otoko, 94.
Ototara stone, 253. (*See also* Oamaru stone.)
Otupae Hill, 111.
Otupi Hill, 111.
Otuwhero Stream, 176.
Outlying islands, 289–91.
Outram, 275.
Owaka, 288.

Owen district, 195.
Owen, Mount, 175.
Owen River, 193.
Owhea or Awhea River, 160.
Oxford County, 233–35, 237.
Oxford district, 233, 234.
Oxford Hill, 234.
Oxygen, 9, 10.
Oyster Hill, 240.
Oyster Point, 271, 272, 294.

P.

Paerata, 73.
Paeroa, 78, 83.
Pahaoa River, &c., 159, 160.
Pahi, 48, 58, 59, 60, 61, 62.
Pahiatua County, 148–50.
Pahiatua district, &c., 148, 149, 150.
Pairatahi, 40.
Pakaraka, 47.
Pakaurangi Point, 61.
Pakawau, 165.
Pakihi Island, 71.
Pakipaki, 112, 113.
Palliser Bay, 159, 160, 161.
Palliser Cape, 160.
Palmer Range, 242.
Palmer's Creek, 63.
Palmerston North, 143, 147.
Palmerston (Waihemo Co.), 254, 267 *et seq.*
Pandora Point, 113.
Papa, 17, 18, 92, 97, 118, 126, 167, 168, 185.
Papakaio, 253.
Papakamai, 227.
Papakotai Hills, 46.
Papakura, 71, 72, 73.
Papakura limestone, 72.
Paparoa (Otamatea Co.), 58, 59, 60.
Paparoa (Wanganui River), 118.
Paparoa County, 238–39.
Paparoa Range, 209.
Parakao, 55.
Parakino, 132.
Parapara district, &c., 165, 166, 167.
Parapara Inlet, 165, 166, 167, 169.
Parapara River, 165 *et seq.*
Paraparaumu, 134, 162, 163.
Parengarenga, 36, 37.
Pareora district, 249.
Pareora River, 246, 248, 249, 250.
Parihâka, 47.
Parikawa, 183.
Parikawakawa, 183.
Paringa River, 224, 229, 230, 231.
Pariwhakaoho Stream, 170.
Parnassus, 207.
Parua Bay, 51.
Passage Island, 278.
Patangata County, 112, 140–41, 146.
Patangata district, &c., 140, 141.
Pataua River, 56.
Patea County, 124, 130–31, 133.
Patea district, &c., 129, 131.
Patea River, 123, 128, 130, 131.
Paterson Inlet, 288.
Patokatoka, 115, 117.
Paturau River, 165, 167, 169.
Patutahi, 96, 97, 98.
Peebles, 252.
Peel, Mount, 170, 184, 192.
Pehiop (pa), 105.
Pelorus Sound, 181, 183.
Pembroke, 263, 265.
Peninsula County, 273, 276–77, 293.
Pensini Creek, 187.
Percy Smith, Mount, 251.
Permo-Carboniferous rocks, 174, 178, 183, 292.
Perseverance Harbour, 289, 290.
Petane, 111, 112.
Peter Ridge, 212.
Phosphate of lime, &c., 2, 7, 13, 15, 18, 30, &c.
Phosphate rock, 15, 18, 112, 285, 291.
Phosphatic limestone, 7, 80, 81, 108, 206, 219, 255, 256, 289.
Phosphoric anhydride, 15.
Phosphorite, 15, 19. (*See also* Collophane.)
Piako County, 84.
Piako Plain, 77, 84.
Piako River, 76, 84, 88.
Piave River (Italy), 244.
Picton, 182, 183, 203.
Picton Bay, 182.
Pig Gully, 182, 202.
Pikikiruna Range, 170, 171, 174, 175, 176, 180.
Piopio, 106.
Pipiriki, 126.
Pirau Stream, 44, 45.
Pirikawa, 183.
Pirinoa, 160, 161.
Pirongia, Mount, 79, 80, 86, 103.
Pisolite, pisolitic limestone, 22.
Pitt Island, 289.
Plants (*see also* Lime-kilns; Lime-works)—
    For calcination of limestone, 7, &c.
    For pulverization of limestone, 7, 8, 9, &c.
    Large, central, 8–9.
    Small, local, 8–9.
Pleasant Point, 248.
Pleasant River, 268, 271, 272, 294, 295.
Plenty, Bay of, 89, 90.
Poerua, 217.
Pohangina County, 137–38.
Pohangina River, 137, 138, 143.
Pohara, 170 *et seq.*
Pohui, 111.
Point Elizabeth, 212, 213, 216.
Poison Bay, 259.
Pokako, 119.
Pokapu, 46.
Pokeno, 78, 83.
Pomahaka district, 288.
Pongaroa, 151.
Ponui Island, 71.
Poor Man Creek, 178, 180.
Popuanui trig. station, 121, 125.
Porangaki or Pourangaki Stream, 137.
Porarari River, 174 (footnote), 188.
Porirua Harbour, 162.
Poro-te-Koihama Stream, 44.
Port Albert, 63.
Port Awanui. (*See* Awanui.)
Port Chalmers, 272, 273.
Port Lyttelton. (*See* Lyttelton.)
Port Molyneux, 288.
Port Nicholson, 163.
Port Pegasus, 288.
Port Robinson, 206, 207.
Port Underwood, 183.
Port Waikato, 83.
Porter River, 232.
Porter's Pass, 233.
Portobello, 276, 294.
Potash, 3, 7, 16.
Potash liberated by lime, 3.
Potash manures, when necessary, 3
Pothole Creek, 226.
Potts, Mount, 243.
Pouakai Range, 119.
Poukaua Valley, 113.
Poukawa, 153.

Pourangaki Stream, 137.
Poverty Bay, 92, 96, 97, 98. (*See also* Gisborne.)
Power, electric, 9, 231.
Presentation, method of, 35.
Problems in use of lime, &c., 5–9.
Puhipuhi, 47.
Puhipuhi River, 203, 204.
Pukaki Lake, 258.
Pukapuka, 64.
Pukehemoa Stream, 45.
Pukehou, 140.
Pukekaroro, 61.
Pukekura, 114, 141.
Pukemiro, 79, 80, 81.
Puketapu (Hawke's Bay Co.), 112.
Puketapu Hill (Waihemo Co.), 268.
Puketeraki Peninsula, 271.
Puketeraki Range, 233, 234.
Puketitiri, 111.
Puketoa Cliff, 86.
Puketoi Range, 142, 144, 146, 148, 150, 151.
Puketutu, 118.
Pukeuri, 251, 253.
Punakaiki River, 184, 188.
Puponga, 169.
Puponga Point, 69.
Pupuke River, 41.
Purakanui Inlet, 273.
Purangi, 116.
Putaruru, 88, 108.
Puti Point, 86.
Putiki Bluff, 134.
Pyramids, The, 219.
Pyrite or iron-pyrites, 16.

Q.

Quail Valley, 179.
Quarries, limestone. (Not indexed.)
Quarries, marble, 175, 176.
Quarry sampling, 28.
Quartering down, 28.
Quartz, quartz sand, &c., 13, 14, 18, 19, 20, 38, 41, &c.
Quartz Ranges, 167.
Queen Charlotte Sound, 181, 183.
Queenstown, 263.
Quicklime, 3, 5, 6, 7, 9.
Quicklime compared with slaked lime, 5–7.
Quicklime, definition of, 9.

R.

Raetihi, 126.
Raglan County, 79–83, 86, 88.
Raglan district, &c., 80, 82.
Raglan Harbour (Whaingaroa), 79, 80, 83.
Raglan limestone, 80, 82, &c.
Rahotu, 120, 127.
Railways, transport of lime, &c., on, 6, 8.
Rainy Creek, 208.
Rakaia Gorge, 240, 241.
Rakaia Railway-station, 244.
Rakaia River, 239, 240, 241, 242, 244.
Rakanui Stream, 86.
Rakaunui, 151.
Rakautoa, 46.
Ramarama Stream, &c., 46.
Rameka Creek, 171, 173, 174.
Ranfurly, 266, 267.
Rangataua, 126.
Rangaunu Bay, 38, 40.
Rangihaeta Head, 171.
Rangikohua Valley, 106.
Rangiora County, 237.
Rangiora district, &c., 233.
Rangitaiki River, &c., 89.
Rangitata River, &c., 241, 242, 244, 247.
Rangitikei County, 108, 111, 134, 135–37.
Rangitikei River, &c., 108, 111, 135, 136, 137, 143, 144, 146, 147.
Rangitoto, Mount or Island, 66, 69.
Rangitoto–Tuhua Range, 102, 107.
Raorakia or Raorikia, 132.
Rapahoe Range, 212, 213.
Raukokore River, 91.
Raukumara Range, 91, 93.
Raupo, 58.
Raurimu, 119.
Razorback Point, 188.
Reaby, near Croydon, 283.
Readers, advice to, 2.
Red Spur, 196.
Redcliff Gully, 242.
Redvale, 66, 68, 69, 70.
Reefs, The, 275.
Reefton, &c., 208.
Reid's Creek, 243.
Reidston, 253.
Repongaere, 97.
Reporua, 92.
Retaruke River, &c., 118.
Richmond Flat, 167.
Rimutaka Range, 160, 162, 163.
Riverton, 280.
Riwaka district, &c., 135, 175, 176, 177.
Riwaka River, &c., 175, 176, 180.
Roads, materials for, 65.
Robinson, Port, 206, 207.
Rocklands, 187.
Rocks, constitution of, 13.
Rocky Point (Thames Co.), 76, 77.
Rocky Point (Waiapu Co.), 92.
Roding Valley, &c., 178, 179. 180.
Rodney County, 58, 61, 63–66.
Roger Creek, 187.
Rolling River, 177.
Roporua, 92.
Rose Mount, 187, 210.
Ross, 211, 217, 224, 226, 227, 228, 229, 230, 231.
Ross, lime-works at, 228–29.
Rotomanu, 217.
Roto Ngaro (lake), 79.
Rotorua County, 89.
Rotorua district, &c., 89, 108.
Rough Creek, 209.
Roxburgh, 265.
Roy's Peak, 262.
Ruahine Range, 108, 111, 134, 135, 136, 137, 138 140, 142, 143, 144, 147, 148.
Ruakaka River, 49, 54.
Ruamahanga Plain, 157.
Ruamahanga River, 159.
Ruapehu, Mount, 118, 126, 134, 136.
Ruapekapeka Range, 46.
Ruatahuna, 89.
Ruataniwha, 165.
Ruawai, 58.
Rugged Island, 288.
Runaway, Cape, 90, 92.
Russell, 46.

S.

Saddle Creek, 230.
Saddle Hill, 273.
St. Andrew Stream, 186, 190.
St. Arnaud Mountains, 192, 195.
St. David Stream, 186.
Saltwater Creek, 216, 217.
Samoa, 291.
Samples, collection of, 26–30.
Samples, empirical, 27, 30.

Samples, grab, 27.
Samples, labelling, 28, 29.
Sampling limestone, 26–30, 38.
Sampling, systematic, 28–30.
Sand, calcareous, 37, 40, 290.
Sandhill Creek, 167, 168.
Sandhills. (*See* Dunes.)
Sandy Bay, 175, 176.
Sandymount, 276, 277.
Saxby Hill, 94.
Scargill, 222, 223.
Scarlett, Mount, 185.
Scientific language, 12.
Scinde Island, 111, 112, 293.
Seacliff, 271.
Seaford, 169.
Seal Point, 277.
Seatoun, 162.
Seaward Kaikoura Mountains, 195.
Seddonville, 186, 191, 192.
Sedimentary rocks, 23, 24, 26.
Sellen's homestead, 178, 179.
Selwyn County, 239–41.
Selwyn River, &c., 238, 239.
Separation Point, 174.
Septaria, 118, 161, 205. (*See also* Concretions.)
Serpentine River, 178.
Seymour River, 201.
Shades Creek, 197.
Shag Bay, 42.
Shag Point district, &c., 252, 256, 269, 270.
Shag River, &c., 268, 293.
Shakespeare Bay, 182.
Shakespeare Cliff, 134.
Sheffield, 233.
Shells as source of lime, &c., 17–18, 37, 38, 40, 47, 62, 64, 69, 72, 73, 77, 85.
Shells, phosphatic, 18.
Shelly sands, 37, 40, 290.
Sheriff River, 193.
Sherwood Station, 196.
Shotover River, 265.
Sibbald's Quarry, Caversham, 294.
Silica, 14.
Silicates, 13.
Siliceous limestone, 61, 165, &c.
Silicified limestone, 23, 64, 93.
Silverdale or Wade, 66, 67, 68, 70.
Silverhorn (mountain), 260.
Silverstream (Hutt Co.), 168, 169.
Silverstream (Taieri Co.), 273, 274.
Sinclair Head, 163.
Sinter, calcareous. (*See* Travertine.)
Sinter, siliceous, 22.
Skelton's Hill, 60.
Skippers, 263.
Slaked lime. (*See* Lime, slaked.)
Slate Creek (Westland Co.), 226.
Slate River (Collingwood Co.), 165.
Slickensides, 39, 57, 67.
Slip Stream, 94.
Slippery or Hay Creek, 72, 73.
Slope débris, talus, &c., 23, 198, 199, 200, 220, 223, 248. (*See also* Limestone, friable or soft.)
Slug Creek, 187.
Smart, Mount, 101.
Smith's Creek, 46.
Smoothwater Creek, 230.
Smyth Creek, 226.
Snares Island, 291.
Soda, 16.
Soft limestone. (*See* Limestone, friable or soft.)
Soil—
  Exhaustion of, by excessive application of lime, 3.
  Lime needed by, 2, 3.
  Wealth produced by, 1.
Somers, Mount, 242, 243, 292.
Sounds County, 181.
South Canterbury, 246, 247, 250, &c.
South Makara, 162.
South or Perseverance Harbour, 290.
South Taranaki Bight, 135.
Southern Alps, 195, 211, 224, 239, 241, 244, 245, 251.
Southland County, 281–84, 290.
Southland, old Provincial District of, 288, 292, 293, 294.
Spar, dog-tooth, Iceland, nailhead, 17. (*See also* Calcite.)
Spenser Mountains, 192, 195.
Sphinx Rock, 193.
Spirits Bay, 36, 37.
Springburn, 242, 243, 244.
Springfield, 232, 233.
Springs County, 238–39.
Squire's farm, 248, 250.
Stalactites and stalagmites, 17, 20, 21, 22, 23, &c.
Stanton River, 196.
Staveley, 243.
Stewart Island, 288–89.
Stillwater Creek, &c., 212, 213, 217.
Stillwater Junction, 213, 217.
Stirling, 287.
Stony Creek (Awakino Co.), 99, 101.
Stony Creek (Lake Co.), 260.
Stony or Te Wharau River (Inangahua Co.), 187, 209.
Stonyhurst homestead, 218.
Stratford County, 121–25, 128, 129, 133.
Stratford Creek, 179.
Stratford district, &c., 120, 123, 124.
Strathmore, 121, 125.
Strath Taieri, 266, 273.
Stratification, definition of, 26.
Strawberry Point, 61.
Strike, definition of, 26.
Studholme Junction, 251.
Sub-antarctic islands, 291. (*See also* Outlying islands.)
Sullen's. (*See* Sellen's.)
Sulphur, 16.
Sumner, Lake, 217.
Sutherland Sound, 263.
Sutherland's, 248.
Swale River, 201.
Sylvester Creek, 212, 213.
Systems, geological, 23–26.

T.

Table of geological systems, 25.
Tagliamento River (Italy), 244.
Tahaenui, 110.
Tahakopa, 288.
Taieri County, 271, 272, 273–76.
Taieri Plain, 273.
Taieri Plain, Upper, 266, 273.
Taieri River, 275, 287.
Taihape, 135, 136, 137.
Taihore Road, 121.
Taipo Range, 157.
Taipos (hills), 156, 157.
Takaka County, 165, 170–74, 175.
Takaka district, &c., 171.
Takaka River, &c., 170, 171, 173, 174, 184.
Takapau, 139, 140, 142, 143, 145, 147, 150, 152.
Takapuna, 69.
Takatahi, 86.
Takoratea Hill, 92.
Talus or slop deposits, 23, 198, 199, 200, 220, 223, 248.
Tamaki River, 71.
Taneatua, 90.

Tangarakau Stream, Gorge, &c., 117, 125, 126.
Tangitu Creek, 41.
Tangoio, 112.
Tangowahine, 56, 57.
Tansey Creek, 212, 215.
Tapanui, 285, 288.
Tapu, 76.
Tapuae Creek, 119.
Tarakohe, 172, 173, 174.
Taramakau River, 212, 213, 224, 231.
Taramakau Settlement, 213, 215.
Taramokau or Taramoukou Stream, 117.
Taranaki Bight, South, 135.
Taranaki County, 119–21, 127.
Taranaki, old Provincial District of, 134, &c.
Taranaki Point (Kawhia Co.), 79.
Tararu, 77.
Tararua Range, 134, 147, 148, 152, 154, 156, 159, 160.
Taratu Coal-mine, 287.
Tarawera (East Taupo Co.), 108.
Tarawera, Mount, 89.
Tarawhati, 44.
Taringatura Range, 279.
Taruarau Spur, 111.
Tata Islands, 171, 172, 173.
Taueru, Taueru limestone, 157, 158, 159, 160.
Taumarunui, 107, 108, 118, 126.
Taumatataire Hill, 100.
Taupiri, 79.
Taupiri Gorge, 83.
Taupo County, East, 108–9.
Taupo County, West, 107–8.
Taupo, Lake, 88, 107, 108.
Tauranga Bay (Buller Co.), 187, 188, 191.
Tauranga Bay (Whangaroa Co.), 37, 42.
Tauranga County, 85.
Tauranga district, &c., 78.
Tauranga Harbour, 85.
Tauri Kura Bay, 51.
Tawairoa Range, 102.
Tawera County, 232–33, 239.
Taylor, Lake, 217.
Taylor's Pass, 181, 197.
Te Akatea or Glen Massey, 79, 82, 88.
Te Akau, 80.
Te Anau, Lake, 278, 279, 280.
Te Apiti, 141.
Te Arai, 97.
Te Araroa, 92, 93.
Te Aroha, 84.
Te Aroha Stream, 97.
Te Aute or Opapa, 112, 113.
Te Aute limestone, 111, 138, 139, 141.
Te Awaite, 160.
Te Awamutu, 88.
Te Hara Point, 79, 80.
Te Haroto, 108.
Te Kaha, 90.
Te Karaka, 95.
Te Karu Creek, 43.
Te Keru, 91.
Te Koau Point, 91, 92.
Te Kuiti district, &c., 83, 84, 88, 89, 99, 101, 103 *et seq.*, 118, 119, 120, 124, 125, 126, 129, 135.
Te Kuiti limestone, 99, 101, 102 *et seq.*
Te Mata (Hawke's Bay Co.), 112, 113.
Te Mata (Raglan Co.), 82.
Te Mata Point (Whangara Co.), 52.
Te Mika Peninsula, 86.
Te Miko Cliff, 188.
Te Moana, Upper, 247.
Te Opu, 62.
Te Paka or Scargill, 222, 223.
Te Puke, 85, 90.
Te Rau-a-moa, 85, 87, 102.
Te Reinga, 109, 110.
Te Reinga Falls, 109, 110.
Te Roti, 128.
Te Waewae Bay, 279.
Te Waka Range, 111.
Te Wera, 125, 130.
Te Whaiti, 89.
Te Whanga Lagoon, 289.
Te Wharau, 158, 159.
Te Wharau or Stony River, 187, 209.
Te Wharu Bay, 86.
Te-ana-hohonu Cave, 86.
Teaneraki, 255, 257.
Tengawai River, 245.
Tenui or Tinui, 156
Te-pura-pura, travertine at, 161.
Terakohe. (*See* Tarakohe.)
Terore awairoa (rocks), 106.
Teschemaker's, 253.
Thames County, 76–77.
Thames district, &c., 76, 77.
Thames, Firth of, 73.
Thames or Waihou River, 76, 78, 85, 88.
The Castles, 167, 168.
The Elevation, 182.
The Gorge Railway-station, 144, 147.
The Two Brothers, 242.
The Whau, 71.
Thomas, Mount, 235.
Thomas River, 232.
Thompson's Sound, 278.
Thornbury, 280.
Three-channel Flat, 186, 187.
Tikorangi Hill, 53, 54.
Timaru, 243, 245, 246, 248, 249.
Tinakori Road, 162.
Tinui or Tenui, 156.
Tiraumea Stream, &c., 151, 153.
Tirua Point, 99.
Tokatoka, 56, 57, 58.
Toko, 122, 123, 124, 125, 128.
Tokomairiro or Milton, 285, 286, 294.
Tokomairiro Plain, &c., 285, 286.
Tokomaru (Waiapu Co.), 92, 93.
Tokomaru (Horowhenua Co.), 152.
Tokorahi, 258.
Tolaga Bay, 96, 98.
Tom Bowline (or Bowling) Bay, 36.
Tomo (= holes or caves), 105.
Tone River, 198.
Tongaporutu River, 117.
Tongariro, Mount, 118.
Torehine, 74, 75.
Torekiapokia Stream, 94.
Torlesse, Mount, 198.
Totara (Waitaki Co.), 254, 255.
Totara Flat (Grey Co.), 210, 216, 217.
Totara Point (Kawhia Co.), 86.
Totara River (Buller Co.), 188.
Totara River (Westland Co.), 226.
Totoro, 117.
Totoro Road, 106.
Towai, 46.
Towai Creek, 41.
Transport, means of, cost of, 5, 6, 8, 10, 1 , &c. (*See also* Counties.)
Transport, problem of, 8.
Travertine, 17, 20, 22, 23, 43, 47, 97, 98, 119, 127–28, 149, 155, 161, 162, 179, 180, 193, 194, 200, 202, 212, 229, 265, 292.
Trelissick Basin, 198, 232, 233.
Tripp's Pass, 245.
Tuakau, 82.
Tuapeka County, 284–85, 288.
Tuapeka Mouth, 285.
Tuatapere, 280.
Tucker or Perseverance Cove, 290.
Tuff or tufa, calcareous, 17. (*See also* Travertine.)

Tuhua Range, 102, 107.
Tukurua Point, 169.
Tukurua Stream, 166.
Tuparoa, 92.
Turanga Creek, 71.
Turanganui, 161.
Turnagain, Cape, 141, 146.
Turnbull's iron lease, 166.
Turntable Hill, 47.
Tutaekuri River, 112.
Tutamoe, 57.
Tutira Block, 112.
Twelve Apostles Range, 212.
Twelve-mile or Few's Creek, 259, 260, 263.
Two Brothers, The, 242.
Tycho Valley, 249.

U.

Umangawha Stream, &c., 74, 75.
Underwood, Port, 183.
United Copper Company's tramway, 179.
United River, &c., 178.
Ure River, 198, 201, 202.
Urenui, 117.
Urewera country, 89, 90.
Utakura Stream, 45.
Utapu, 126.
Utiku, 135, 136.

V.

Veins or lodes, calcitic, 22, 39, 53, 57, 59, 63, 65, 67, 73, 75 *et seq*, 90, 93, 94, 98, 229, &c.
Veins or lodes, gold-bearing, 76.
Venice, Venetia (Italy), 244.
Vernon, Mount, 139.
Victoria Valley, 36, 37, 38.
View Hill, 234.
Vincent County, 263, 264–66, 267.
Von Valley, 263.

W.

Wade or Silverdale, 66, 67, 68, 70.
Waerenga-o-kuri, 97.
Waharoa, 84.
Wahi Lake, 79.
Waiapu County, 91–93, 96.
Waiapu River, 92.
Waiareka district or valley, 254.
Waiau district, &c. (North Canterbury), 196.
Waiau Plain, 195.
Waiau River, 196.
Waiau River (Wallace Co.), 279, 280.
Waihanga or Waiohanga Creek, 45.
Waihao Downs, 250, 251.
Waihao Forks, 249.
Waihao River, &c., 249, 250.
Waiharakeke Creek, 45.
Waiheke Island, 71.
Waihemo County, 252, 256, 268–70, 271.
Waihemo district, &c., 268, 294.
Waihemo Valley, Upper, 269.
Waihi, 77, 78.
Waihi Goldfield, 22.
Waihirere, 96, 98.
Waiho River, 231.
Waihola Gorge, 285, 287.
Waihola Lake, 273.
Waihola limestone, 287.
Waihora or Waihola Lake, 273.
Waihou River (Hokianga Co.), 43.
Waihou River (Thames Co.), 76, 78, 85, 88.
Waihuka River, 94.
Waikaia, 281.
Waikaka, 281.
Waikakariki Stream, 97, 98.
Waikanae district, River, 152.
Waikaraka Stream, 44, 45.
Waikare, Lake, 83.
Waikare River, 112.
Waikaremoana, Lake, 89.
Waikari district, &c., 218 *et seq.*, 233, 237.
Waikari or Waikare Inlet, 44.
Waikato County, 83–84, 87.
Waikato Heads, 79, 80.
Waikato limestone, 71.
Waikato Plain, Middle, 83, 87.
Waikato, Port, 83.
Waikato River, &c., 73, 79, 81, 82, 83, 87, 88.
Waikawa, 284.
Waikawau, 80.
Waikohu County, 93–96, 98.
Waikohu or Waikopua Creek, 71, 72.
Waikohu River, 94.
Waikonini, 111.
Waikopua Creek, 71, 72.
Waikorai (?), 201.
Waikoromumu Stream, 170.
Waikouaiti Bay, 273.
Waikouaiti County, 271–73.
Waikouaiti district, &c., 271, 272, 273, 275, 294.
Waikouaiti North Head, 271.
Waikuka Creek, 45.
Waikura Valley, 91.
Waimairi County, 238–39.
Waimairie, 186.
Waimakariri River, 244.
Waimamaku River, &c., 43, 44.
Waimangaroa, 191.
Waimarama or Waimirima, 112.
Waimarino County, 126–27, 132, 136.
Waimarino district, &c., 119, 126.
Waimate County, 245, 248, 249–51, 252, 253.
Waimate district (Waimate Co.), 249, 251.
Waimate district (Waimate West Co.), 128.
Waimate North (Whangaroa Co.), 45, 250.
Waimate West County, 128, 129.
Waimea County, 170, 174–81, 194.
Waimea Plain (Waimea Co.), 175, 180.
Waimea Plain (Southland Co.), 281, 282, 288.
Waimea Railway-station, 282.
Waimea River (Waimea Co.), 180.
Waimiha, 108, 119.
Waingarara, 90.
Waingaro, 79, 80, 81, 82.
Waingaro River, 171, 173.
Wainui or Herbertville, 141.
Wainui-o-mata Stream, 162.
Waiohanga Creek (Thames Co.), 77.
Waiohanga or Pirau Stream (Bay of Islands Co.), 44.
Waiomio, 46, 47, 51.
Waiomo, 76.
Waiongona-iti Stream, 119.
Waiouru, 126, 134, 135.
Waipa Collieries, 88.
Waipa County, 87–88.
Waipa district, 105.
Waipa River, 79, 80, 83, 85, 87, 88, 102, 106.
Waipahi Junction, 288.
Waipaoa River, 93, 94.
Waipapa (Kaikoura Co.), 205.
Waipapa River gorge, 44.
Waipapa Stream (Clifton Co.), 116.
Waipara County, 197, 217–24, 233, 234, 236, 237, 238, 247.
Waipara County, soft limestone of, 219–20, 223.

Waipara district, &c., 218, 219, 223, 236, 243.
Waipara River, 198, 218, 219, 236.
Waipatiki, 146.
Waipatiki Valley, &c., 112.
Waipawa County, 112, 138–40, 141, 143.
Waipawa district, 138.
Waipawa Gorge, 139.
Waipawa River, 138, 139.
Waipiro, Waipiro or Open Bay, 92, 93.
Waipori Lake, 273.
Waipu district, &c., 49, 54.
Waipukapuka Stream, 77.
Waipuku, 124.
Waipukurau County, 138–40, 141.
Waipukurau district, &c., 138, 139, 140.
Waipunga Stream, 108.
Wairakaia, 98.
Wairarapa limestone, 160.
Wairarapa Plain, 157, 160, 161.
Wairarapa Valley, 161.
Wairarapa South County, 158–59, 160.
Wairau River, &c., 181, 182, 183, 195, 203.
Wairere Falls, 102, 106.
Wairewa County, 238–39.
Wairoa County, 108, 109–10, 111.
Wairoa district, &c. (Wairoa Co.), 109, 110, 114.
Wairoa district, &c., Northern, 292, 294.
Wairoa Gorge, River, &c. (Waimea Co.), 178, 179, 180.
Wairoa River, Northern, 56, 58.
Wairoa South, 64, 72.
Wairua River, 49, 56.
Waitaha River, Settlement, 230.
Waitahu River, 208.
Waitakeri Range, 66.
Waitakeri or Nile River, 188.
Waitaki County, 251–58, 268, 269.
Waitaki Plain, 252, 258.
Waitaki River, &c., 249, 251, 252, 253, 258.
Waitaki stone, 253, 255.
Waitangi Series, 42, 44.
Waitangi Stream, 45.
Waitapu, 174.
Waitara district, &c., 116, 117, 120.
Waitara River, 116, 119.
Waitati or Blueskin Bay, 271, 273.
Waitati Stream, 271.
Waitekauri, 77, 78.
Waitemata County, 66–70, 71.
Waitemata or Auckland Harbour, 66, 70, 71.
Waitemata series or beds, 66, 71, 73, 79.
Waitewhena district, valley, &c., 118.
Waitohi, Upper (Geraldine Co.), 247.
Waitohi Valley (Sounds Co.), 182.
Waitomo caves, 86, 102.
Waitomo County, 83, 84, 85, 100, 102–7, 108, 115, 118, 120, 125, 126, 128.
Waitomo district, 107.
Waitomo Stream, 102.
Waitotara County, 124, 126, 129, 130, 131–34.
Waitotara district, &c., 128, 130, 131, 133.
Waitotara River, 130, 131, 132.
Waiuku, 73.
Waiwiri Road, 116, 122, 123.
Waiwiri Stream, 122.
Wakamarama Range, 165.
Wakarara Range. (*See* Whakarara.)
Wakatipu Lake, district, &c., 259, 260, 262, 263, 265, 292, 293, 294.
Wakefield, 178.
Wakefield Gully, 165.
Wallace County, 279–81, 284.
Wanaka, Lake, 262 *et seq.*
Wandle River, 222.
Wanganui Bight, 135, 146.
Wanganui coastal plain, 134, 135, 143, 146, 147, 162.
Wanganui County, 134–35, 136.
Wanganui River, 106, 118, 119, 125, 126, 132, 133, 134, 135.
Wanganui Town, district, 131, 132, 133, 134, 135, 137.
Wanganui River, Big. (*See* Big Wanganui.)
Wanganui River, Little. (*See* Little Wanganui.)
Wangapeka district, River, &c., 177, 180, 193.
Wanstead, 141.
Ward district, &c., 183, 197, 198, 199, 200, 202.
Warea, 126.
Warkworth, 38, 63, 64, 66, 72.
Waro, 48, 49.
Washbourn Block, 166.
Washdyke (near Timaru), 243.
Washdyke Creek, 183.
Wataroa district, River, 231.
Waverley, 130.
Weber, 142, 146.
Weber County, 146.
Weiti Stream, 67.
Weka Pass, Weka Pass Creek, &c., 204, 218, 219 *et seq.*, 237, 292, 294.
Weka Pass stone, 204, 218, 219, 220, 221, 223, 236, 247.
Wellington, 120, 152, 163.
Wells Creek, 230.
Wellsford, 63.
Welshman's, 216.
Weraroa Stream, 94.
Westhaven or West Wanganui Inlet, 169.
Westland County, 224–32, 264.
Westland, old Provincial District of, 224, &c.
West Oxford, 234.
Westport, 187, 191, 192, 211.
West Taupo County, 107–8.
Whaingaroa or Raglan Harbour, &c., 79, 80, 83, 105.
Whakanekeneke Stream, 45.
Whakapirau, 58, 62.
Whakapunake, 98.
Whakarara or Whakarare Range, 112, 138.
Whakatane County, 89–90, 91, 108.
Whakatane district, 89, 90.
Whakatane River, &c., 89.
Whalebone Creek, 77.
Whangamata, 78.
Whangamomona County, 121, 125–26, 133.
Whangaparaoa, 92.
Whangape Harbour, 43.
Whangape Lake, 79.
Whangarei County, 46, 48–56.
Whangarei district, &c., 38, 44, 47 *et seq.*, 58.
Whangarei Harbour, 49.
Whangarei Heads, 49, 51.
Whangarei limestone, 48 *et seq.*, 58, 72, 86.
Whangaroa County, 41–43.
Whangaroa district, &c., 41.
Whangaroa Harbour, 37, 41, 42, 56.
Wharanui, 183, 202.
Whare Flat, 274.
Wharekuri, 249, 253, 258.
Whareora, 49, 50.
Whareorino Mountain, 99.
Whareponga, 92.
Wharerangi, 112.
Whatatutu district, oil springs, 93, 94.
Whau, The, 71.
Whauwhau Valley, 48, 52.
Whenuakura River, 130, 131.
Wheturua Hill, 94.
Whitcombe Pass, 240, 241.
White, Mount, 232, 233.
Whiteburn, 142.
Whitecliffs (Clifton Co.), 117.
Whitecliffs (in Malvern Co.), 239, 240.

White Rock quarries (Ashley Co.), 235. 236.
White Rock Station (Featherston Co.), 160, 161.
White Rock Stream (South Canterbury), 250.
Whitford, 72.
Wilberforce Goldfield, 241.
Wilberforce River, &c., 240.
Wilkie's farm, 132.
Wilson River, 278.
Wimbledon, 146.
Wingatui, 266, 275.
Winton, 262, 281, 292.
Wiremu Road, travertine near, 127–28.
Wooded Peak, 178.
Woodthorpe, 112.
Woodville County, 144–46.
Woodville district, &c., 144, 145, 152.

INDEX II.—PERSONAL NAMES, INCLUDING COMPANIES, ETC.

A.

Adams, J. H., 74, 76, 94, 95.
Adkin, G. L., 152.
Ainsworth, W. F., 291.
Aitchison, E., 161.
Akitio County Council, 151.
Allen, D. V., 74.
Amner and Sons, 114.
Anderson, J. G.. 31.
Andrew, A. R., 285, 286, 287.
Andrew, J. C., 156.
Armstrong, W. H., 87.
Arthur and Docherty, 229.
Aspinal, J., 113.
Aston, B. C., 3, 8, 23, 30, 31, 32, 33, 34, 59, 63, 70, &c.
Atkinson, D., 50, 53, 64, 120, 133.
Auld, W. B., 210.

B.

Bacon, S., 43, 153.
Bain, H. F., 31.
Baker, A. J., 106.
Baker, S., 82.
Ball, T., 37, 292.
Barker, C. S., 289.
Barron, A., 224.
Bartle, H., 127.
Bartrum, J. A., 71, 79, 85, 186, 192, 215.
Bassett, J., 166.
Basstian, C., 280, 293.
Bayfield, A. D., 133, 179.
Baylis, G. de S., 32, 33.
Bell, A. D., 268.
Bell, A. W., 179.
Bell, J. M., 37, 76, 117, 118, 119, 154, 163, 170, 171, 180, 194, 217, 231, 232.
Benham, W. B., 69.
Bickerton, A. W., 239.
Bidwill, J. C., 109.
Birch, —, 136.
Birks, R. L., 67.
Black, J. G., 30, 235, 243, 250, 256, 257, 268, 272, 276, 280, 287.
Blackburne, Smith, and Co., 242.
Blaine, J. B., 145, 149.
Blair, W. G., 254.
Blair, W. N., 239, 240, 257, 264, 265, 266, 269, 272, 275, 276, 277, 287.
Blake, S. J., 57.
Bleininger, A. V., 31.
Blood, T., 51.
Blundell, R., 45.
Boult, C. N., 276, 277.
Bowron, S. W., 199.
Breese, —, 63.
Brenchelly (?Brenchley), T. F., 155.
Brenchley, T. F., 155.
Bridson, T. A., 67.
Broadgate, F. K., 163.
Broderson, F., 155.
Brown, C., 165, 189.
Brown, H. H., 120.
Brown, J., 3.
Buchanan, J., 134, 285.
Buchanan, M., 159.
Buckman, H. O., 3.
Buehler, H. A., 31.
Buick and Russell, 142.
Buller County Council, 189, 190.
Burgess, H. E., 94.

C.

C. and B., 257.
Cairns, —, 257.
Calder, H., 272, 274, 294.
Cameron, —, 157.
Carey, G. H., 272.
Carne, J. E., 34.
Carswell, D., 157.
Carter, G. H., 67, 68.
Carvell, S., 113.
Chapple, J., 68.
Chaytor, B., 183.
Clark, W., 161.
Clark, W. B., 31.
Clarke, E. de C., 37, 41, 43, 44, 70, 72, 73, 119, 121, 170, 171, 180, 194.
Clark-Walker, G., 55.
Cockayne, L., 147, 152, 163.
Colbeck, Captain, 59, 60, 61.
Cook County Council, 96, 97.
Cooke, H. R., 61.
Cooper, W. H., 112.
Copeland, C. A., 142.
Cotton, C. A., 56, 72, 163, 183, 203, 206, 233, 237, 264, 266, 267, 276.
Cottrell and Kennedy, 197.
Cox, S. H., 48, 49, 50, 51, 52, 54, 57, 58, 60, 63, 65, 66, 73, 79, 80, 92, 151, &c.
Craig, J. J., 46, 51, 80, 81.
Crawford, J. C., 118, 119, 127, 134, 137, 138, 148, 151, 152, 156, 161, 162, 163.
Croft, T., 236.
Cropp, —, 226.
Curley, J. R., 68.
Cussen, L., 84, 88, 89, 107, 118, 119.

D.

Dalgleish, C. S., 227, 228.
Dassler, W., 142.
Davidson, J., 201.
Davis, E. H,. 178.
Denniston, R. B., 276.
Dent, —, 50.
Deverell, W., 36.
Dickson, H., 209, 210, 213, 227, 228.
Dieffenbach, E. W., 109, 128, 133.
Docherty, W., 229, 230.
Dodson, —, 183.
Dominion Cement Company, 49, 54.
Dominion Lime Company, 286.

Douglas, C., 230, 231, 232.
Douglas, J., 250.
Douglas, T. L., 250.
Drew, S. H., 133.
Drummond, —, 177, 180.
Dun, W. S., 208.
Duncan, J., 262.
Dunn, J. S., 114.
Du Toit, A. L., 33.
Dye, F., 66.
Dyson, —, 109.

E.

Earwaker, —, 69.
Eliott, J. W., 259.
Elliott, J., 101.
Ellis, —, 177.
Ellis Bros., 280.
Elmsly, F., 38, 39.
Enys, J. D., 232, 247.
Evans, J. E., 64.
Evans, R., 237.

F.

Farmers' Union, Ballance, 150.
Farquharson, R. A., 279, 281.
Field, G. E., 179.
Fifield, Messrs., 177.
Finlayson, A. M., 264, 266, 267, 270.
Fippin, E. O., 3.
Foley, —, 69.
Forbes, G. W., 207.
Forbes, H. O., 239, 249.
Ford, —, 239.
Fox, C. E., 70.
Fox, E., 188.
Franklin, S., 141.
Fraser, C., 74, 76, 77, 78, 217, 231.
French, —, 172.
Fuller, W., 46.
Furniss, J., 81.

G.

Gaby, H. J., 123.
Gardiner, R., 110.
Garvie, A , 285.
Garvie, T. J., 281.
Gates, —, 103, 104.
Geikie, A., 21, 24.
Gelston, A. J., 57.
Gibbs, F. G., 167.
Gibson, J., 207.
Gillies, —, 285.
Gisborne Borough Council, 97.
Colden Bay Cement Company, 172, 173.
Goodall, J., 249.
Goodger, J., 265.
Gordon, H. A., 47.
Gorman, J., 283.
Grave, W. G., 263 (footnote).
Gray, T. B., 290.
Green, E. R., 275.
Greymouth Harbour Board, 214.
Gudex, M. C., 233, 245, 246, 248, 249, 250, 251.
Gwatkin, H. O., 122.

H.

Haast, J. von., 30, 195, 197, 205, 223, 231, &c.
Hall, A. D., 3.
Hall, C. T., 202.
Hall-Jones, W., 246.
Hamilton, A., 36, 115, 252, 258, 281.
Hamilton, H., 226, 227.
Hamilton, W. S., 281, 284.
Handyside, F., 151.
Hardcastle, J., 249.
Harrison, J., 51, 55.
Hartree, H., 114, 141.
Hay, D., 31.
Hay, P. S., 272, 276, 287.
Hayes, J., 166, 167.
Hayward, C. E., 55.
Heaphy, C., 76.
Hector, J., 30, 36, 43, 44, 47, 58, 64, 70, 73, 76, 108, 113, &c.
Henare, T., 46.
Henderson, —, 175, 176.
Henderson, D., 161.
Henderson, J., 72, 79, 89, 99, 101, 102, 107, 115, 140, 142, 143, 144, 145, 146, 154, 156, 168, 171, 174.
Hepburn, J., 272.
Higginson, H., 250.
Hikurangi Coal Company, 49.
Hilgard, E. W., 3.
Hilgendorf, F. W., 239, 244.
Hill, H., 98, 108, 109, 110, 111, 114, 115, 134, 136, 137, 140 ,141, 143, 146, 148, 151.
Hill, J., 282, 292.
Hillebrand, W. F., 12.
Hobbs, R., 49.
Hobson, —, 175.
Hochstetter, F. von, 30, 70, 73, 76, 79, 83, 84, 85, 86, 87, 88, 89, 103, 105, 106, 107, 108, 109.
Hodson, D., 262.
Hodson, J., 256, 269.
Hogan, D., 138.
Hogg, A., 145.
Holdich, Thos., 132.
Holland, H. H., 218, 220.
Holmwood, E. L., 158.
Honore, C. J., 87.
Hopkins, C. G., 8.
Hore, S. C., 267.
Horn, F. B. van, 31.
Hugonin, C. P., 175, 176.
Hunt, R. R., 82.
Hunt, W. D., 33, 284.
Hutchinson, D., 255, 256, 257, 292, 293.
Hutton, F. W., 30, 71, 72, 73, 74, 79, 80, 83, 87, 89, 114, 134, 224, &c.

I.

Inangahua Farmers' Union, 208, 209, 210.
Industrial Commission (Greymouth), 214.
Ingram, J., 234.
Iraia te Whaite, 161.

J.

Jackman, H., 61.
Jacobson, T. B., 177.
Jameson, J., 189.
Jeffries, C. A., 62.
Johnston, J. A., 204.
Johnston, S., 139.
Jones, L. J., 34.
Jordan, W. H., 62.

K.

Kells, W. H., 155.
Kelly, —, 55.
Kelly, —, 257.
Kennedy, —, 197.
Kenny, —, 181.
King, N. R., 80.
Kirk, T. W., 74.
Kitson, A. E., 246.
Knowles, C. A., 81.
Kummer, F. W. H., 155.

L.

Lady Barkly Company, 282.
Lake Brunner Oil Company, 215.
Langford, E. B., 169.
Law, C., 199.
Layman, F. E., 31.
Lewis, W. J., 123.
Liffiton, E. N., 133.
Ligar, C. W., 285.
Lilley, H., 50.
Lime Conference, Reefton, 210.
Lindop, A. B., 233, 238.
Lines, E. F., 31.
Lockie, —, 97.
Lockington, E. F., 208.
Longon, M., 38, 40.
Looney, G., 127, 128.
Loughlin, G. F., 31.
Lyde, L. W., 132.
Lyon, T. L., 3.

M.

McArthur, A., 225.
McConnell, P., 32.
McCormick, —, 290.
McCulloch, J. K., 253, 255.
Macdonald, —, 276, 277.
MacDonald, —, 283.
McDonald, —, 293.
MacDonald, A. G., 287.
McDonald, J., (Motupipi) 172, (Milburn) 286.
McDowell, —, 261.
Macfarlane, D., 230.
McGowan, J., 116.
McIntosh, R., 269.
McKay, A., 17, 30, 36, 37, 41, 43, 45, 46, 47, 48, 60, 65, 74, 76, 85, &c.
Mackay, A. R., 136.
McKay, G., 55.
Mackay, J. W., 123.
McKay, R. R., 55.
McKay, W. A., 159, 162.
McLachlan, H., 235.
MacLachlan, R. D., 280.
Maclaren, J M., 76.
Maclaurin, J. D., 138.
Maclaurin, J. S., 57.
McLean, C. S., 87.
McLean, W., 91.
McLeod, H. N., 142, 143, 163, 214.
McTaggart, A., 3, 6, 7, 33, 34, 199, 206, 209, 210, 214, 219, 220, 222, 226, 227, 228, 247, 248, 249.
Maddock, W., 155.
Makgill, R. H., 81.
Mangonui County Council, 38, 39.
Mantell, G. A., 133, 252.
Mantell, W. D. B., 130, 133.
Mappin, F. E., 67.
Marchbanks, J., 148.
Marsden, —, 104.
Marshall, G. M., 267.
Marshall, P., 25, 48, 51, 52, 56, 60, 61, 62, 72, 117, &c.
Mason, W., 272.
Matheson, A., 159.
Matthews, A., 68.
Matthews, E. B., 31.
Mauriceville Lime Company, 154.
Mawson, D., 291.
Maxwell, J. P., 105.
Meek, J. A., 255.
Meek, G. E., 280.
Meek, R., 280.
Meeson, J., 239.
Merton, —, 38, 39.
Metcalfe, F., 62.
Milburn Lime and Cement Company, 269, 277, 285, 286.
Minister of Mines, the, 177, 224, 283.
Molineaux, H. S., 275.
Moore, —, 183.
Morgan, P. G., 31, 50, 56, 59, 60, 63, 64, 82, 97, 104, 121, &c.
Morgan, R. J., 78.
Morrison, H. S., 150, 158.
Morton, W., 140.
Mulgan, E. K., 58, 70.
Mullaly, J. F., 110.
Munro, G., 257.
Murray, H., 81.

N.

Neill, G. H., 44.
Neill, J. C., 46, 51, 52, 53, 63.
Nelson Marble Company, 176.
Ness, J., 177.
Newell-Arber, E. A., 284, 288.
New Zealand Farmers' Union, Cheviot, 207.
New Zealand Farmers' Union, Karamu, 80.
New Zealand Marble and Cement Company, 176.
New Zealand Portland Cement Company, 176.
New Zealand Stone Company (Mount Somers), 243.
Nicholson, —, 45.
Nolan, R. A., 125, 129, 130.

O.

O'Brien, C., 193, 194.
Ogden, —, 239.
Ogdon, H. A. (? Ogden), 239.
Oliver, W. R. B., 291.
Ongley, M., 38, 49, 57, 64, 67, 68, 122, 123, 127, 230, 279, 280, 281, 282.
Ormond, J. D., 113, 140.
Orr, R. A., 283.
Orton, E., 27, 28, 29, 31, 270.

P.

Palmer, —, 63.
Park, J., 25, 48, 56, 58, 60, 61, 62, 70, &c.
Parker, R., 150.
Parry, E., 9 (footnote).
Parry, J. G., 64.
Parsons, H. W., 81.
Peach, A. E., 243.
Peake, J., 224.
Pederson, P., 90.
Peppel, S. V., 27, 28, 29, 31, 270.
Peters, E., 284.
Pettman, A. V., 44.
Pharazyn, R., 134.
Philips, C. A., 147.
Pilcher, E. G , 165.
Poynton, J. W., 166.
Price, A. and G., 49.
Prior, G. T., 290.
Public Works Department (Gisborne), 96, 97; (Te Kuiti) 104, 105; (Mount Somers) 243.
Purnell, C. W., 134.

R.

Rabbit Inspector, Hokitika, 225.
Railway Department (Woodville), 144.
Railway Department Locomotive Superintendent, 179.
Ralph, W. J., 82.
Ranson, D. H. F., 172.
Raupo Farmers' Union, 58.
Ray, C., 72.
Read, G., 284.

Redgate Bros., 68.
Reed, F., 87, 173.
Rees, J., 101.
Rees, J. R., 165.
Rees, W. R., 165.
Reese Bros., 254.
Reeves, R. H. J., 189.
Reid and McDowell, 281.
Renner, G., 204.
Reyburn, J. R., 49.
Rhodes, F. N., 52, 53, 56.
Rhodes, G., 69.
Richardson, E., 245, 248.
Richardson, H., 170.
Riddell, J., 277.
Robertson, —, 257.
Robertson, —, 276.
Robinson, T. H., 162.
Rodger, A. W., 280.
Rogers, A. F., 18.
Ross, D. M., 33.
Rowe, W., 276.
Ruddell, H. R., 55.
Ruddell, W., 55.
Russell, —, 142.
Ryan, J., 151.

S.

Sainsbury, A. G., 67, 68.
Sandford, —, 69.
Sargood, P. R., 262.
Seabrook, H. H., 172.
Seddon, R. J., 90, 101.
Sefton, E., 81.
Sellen, —, 178, 179.
Sennett, A. R., 103.
Seymour, A. P., 182.
Shale, S. H., 255.
Sharp, H. H., 100, 116, 122.
Sherzer, W. H., 31.
Shrewsbury, H., 70.
Sibbald, —, 274, 294.
Simson, —, 38, 40.
Skey, W., 37, 43, 45, 46, 55, 58, 64, 70, 97, 113, 155, 214, &c.
Slattery, J. E., 108.
Smith, D., 37, 40.
Smith, E. M., 101, 102, 123, 124.
Smith, S. P., 110, 114, 289.
Smith, S. R., 69.
Smythe, —, 183.
Sollas, W. J., 76, 158, 159, 162.
Somerville, W., 3.
Southgate, J., 63.
Speight, R., 34, 72, 204, 206, 218, 219, 221, 222, 224, 233, &c.
Squire, Mrs. M., 248, 250.
Starkey, G., 240.
Stewart, J. T., 134.
Stocks, W., 243.
Straw, —, 245.
Strudwicke, S. F., 173.
Superintendent, Auckland Province, 295.
Superintendent, Hawke's Bay Province, 113.
Sutherland, D., 258, 264.
Swindley, A. R. H., 75.
Symonds, J. J., 69.

T.

Talbot, H., 263 (footnote).
Tarr, J. B., 153.
Taylor, C. N., 116.
Taylor, R., 130.
Taylor Syndicate, 215.
Te Kuiti Borough Council, 103, 105.
Te Whaite, Iraia, 161.
Thiele, E. O., 246.
Thomas, A. P. W., 89.
Thompson, —, 63.
Thompson, A., 81.
Thompson, A. G., 57.
Thompson, J. S., 130.
Thomson, A., 199, 200.
Thomson, A. S., 107, 109.
Thomson, G. M., 260.
Thomson, J. A., 130, 131, 175, 201, 202, 203, 249, 250, 251, 273, 284.
Thomson, J. T., 285.
Thorne, G., 56.
Tiffen, H. E., 141.
Todd, J. D., 140.
Toko Lime Company, 123.
Tombleson, J., 95.
Toogood, J. A., 161.
Traill, H. D., 289.
Travers, H., 98.
Travers, H. H., 289.
Trechmann, C. T., 135, 178.
Trewin, J., 62.
T. T. and C. Stone Company, 254.
T. T. Company, 257.
Turner, N. H., 218.
Tyneside Proprietary Company, 216.
Tyree, —, 183.

U.

Ulrich, G. H. F., 30, 264, 273, 276, 277.
Uttley, G. H., 253, 258.

V.

Van Horn, F. B., 31.
Vavasour, H. D., 183.
Vogel, J., 283.
Von Haast, J. (*See* Haast.)

W.

Waipara County Council, 220.
Waitohi Valley Mining Company, 182.
Wakeman, W., 149, 150.
Walker, F. G. H., 62.
Wallace, W. G., 142.
Wanner, J., 146.
Ward, J. G., and Co., 282.
Waters, D. B., 256.
Watson, T., 208.
Webb, E. J. H., 167, 168, 170, 171, 184, 185, 186, 189, 192.
Westland Farmers' Co-operative Lime-producing Company, 228, 229.
Westport Harbour Board, 187.
White, C., 38, 39.
White, G., 55.
Whitehorn, H. S., 170.
Wild, L. J., 31, 34, 204, 206, 218, 221, 222, 224, 236, 237, 284.
Wilkie, D., 132.
Wilson, B. M., 105.
Wilson, H., 234, 235, 236.
Wilson, N., 63.
Wilson's Portland Cement Company, 63, 64, 103, 104.
Woods, H., 201, 203, 206, 241.
Wright, E. F., 243.
Wright, Stephenson, and Co., 281.
Wybergh, W., 33.

Y.

Yates, —, 36.
Young, H. R., 190.

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